The relationship between lab-sprint results and match physical performance in professional male soccer players

Kristian Sørlie Lunde

SUPERVISORS:
Matthew Spencer
Per Thomas Byrkjedal

University of Agder, 2022
Faculty of Health and Sport Sciences
Department of Sport Science and Physical Education

Preface

Writing this master's thesis has been exciting, enjoyable, frustrating, and challenging. Additionally, as soccer has been a huge part of my life since childhood, getting the opportunity to work closely with a professional soccer club has been very motivational, interesting, rewarding, and an experience I'm very grateful for.

I want to say a big thank you to my supervisors, Matthew Spencer and Per Thomas Byrkjedal. Your guidance, tips, and encouraging words have been highly appreciated and have been of huge importance for this thesis. Additionally, I want to thank Andreas Ivarsson for helping me with the statistical analysis.

To my fellow students, thank you for these two years at the University of Agder. Your support, encouragement, and humor have greatly contributed to this being two incredible years.

Furthermore, I want to thank all the participants that contributed to this thesis. Your participation and efforts are highly appreciated, and I wish you good luck for this season.

Lastly, I want to express my gratitude to my family and friends for encouraging me during the process of writing this thesis, and a special thank you to my father for always encouraging and supporting me, both during this writing process and in life in general.

May 2022

Contents

I Abbreviations

II Abstract

III Abstract in Norwegian

IV Structure of the thesis

Part 1: Theoretical background and methodology

Part 2: Research study

Part 3: Appendices

I. Abbreviations

1RM	One repetition maximum
Cm	Centimeter
CV	Coefficient of variation
FEK	Faculty ethics committee
FIFA	Fédération Internationale de Football Association
GNSS	Global navigation satellite system
GPS	Global positioning system
HSR	High-speed running
HZ	Hertz
IMU	Inertial movement unit
Km/h	Kilometers per hour
LPS	Local positioning system
M	Meter
M/s	Meters per second
Mm	Millimeter
NSD	Norwegian center for research data
SD	Standard deviation
SEE	Standard error of measurement
SEM	Standard error of mean

II. Abstract

Aim: This research study aims to examine the relationship between lab-sprint performance and match physical performance in professional male soccer players.

Methods: Eleven professional male soccer players (25.5 ± 3.4 years, 183.8 ± 5 cm, and 78.3 ± 4.9 kg) competing in the second-highest division in Norway participated in this research study. Sprinting performance was assessed by the players performing 30-m linear sprints at an indoor location using dual-beamed photocells, whereas match physical performance was monitored using a 10Hz GNSS device embedded with a 100Hz inertial movement unit (Catapult Vector S7) during seven official matches. Selected match play variables included total playing time, total duration, total distance, meters covered per minute, distance covered by high-speed running (19.8-25.2 km/h), distance covered by sprinting (>25.2 km/h), and maximal velocity (m/s).

Results: Moderate evidence was observed for the association between 5-m lab-sprint performance and distance covered by high-speed running (BF_{10}=4.9). Anecdotal evidence was observed for the association between 10-m, 15-m, 20-m, and 25-m lab-sprint performance and distance covered by high-speed running (BF_{10}=1.00-2.18). Similarly, anecdotal evidence was reported for the association between 10-m lab-sprint performance and peak speed during match play (BF_{10}=1.04), and peak lab-sprint speed and peak match play speed (BF_{10}=2.04).

Conclusion: The majority of the lab-sprint performance parameters did not show more than anecdotal evidence for associations with match physical performance. Thus, the 30-m lab-sprint test used in this research study did not reflect the players' physical abilities during match play.

Keywords: Elite football players, laboratory testing, sprint capacity, player monitoring, match play performance, high-speed actions.

III. Abstract in Norwegian

Hensikt: Hensikten med denne avhandlingen er å undersøke sammenhengen mellom sprintprestasjon målt i lab og fysisk prestasjon i kamp for mannlige profesjonelle fotballspillere.

Metode: Elleve profesjonelle fotballspillere (25.5 ± 3.4 år, 183.8 ± 5 cm, and 78.3 ± 4.9 kg) som spiller på det nest øverste nivået i Norge deltok i studien. Sprintprestasjon ble målt ved at spillerne gjennomførte lineære sprinter over 30 m. Sprintene ble gjennomført innendørs og målt ved bruk av dobbeltstrålende fotoceller. Fysisk prestasjon i kamp ble målt ved bruk av 10Hz GNSS enheter med innebygd 100Hz IMU (Catapult Vector S7) i syv offisielle kamper. De utvalgte kampvariablene bestod av total spilletid, total varighet, total tilbakelagt distanse, meter løpt per minutt, distanse tilbakelagt ved høyintensitets løp (19.8-25.2 km/t), tilbakelagt distanse ved sprint (>25.2 km/t), og maksimal hastighet (m/s).

Resultater: Det ble funnet moderat bevis for sammenhengen mellom 5-m sprintprestasjon målt i lab og høyintensitets løp i kamp (BF_{10}=4.9). Anekdotisk bevis ble funnet for sammenhengen mellom 10-m, 15-m, 20-m, 25-m sprintprestasjon målt i lab og høyintensitets løp i kamp (BF_{10}=1.00-2.18). Videre ble det også observert anekdotisk bevis for sammenhengen mellom 10-m sprintprestasjon målt i lab og toppfart i kamp (BF_{10}=1.04), og toppfart målt i lab og toppfart målt i kamp (BF_{10}=2.04).

Konklusjon: Majoriteten av lab-sprint parameterne viste ikke mer enn anekdotiske bevis for sammenhengen med fysisk prestasjon i kamp hos profesjonelle mannlige fotballspillere. Dermed evnet ikke 30-m lab-sprint testen som ble brukt i denne studien å reflektere spillernes fysiske prestasjon i kamp.

Nøkkelord: Elite fotballspillere, laboratorietesting, sprint kapasitet, spillerovervåkning, kamp prestasjon, høy-intensitets bevegelser.

IV. Structure of the thesis

The structure of this master’s thesis consists of three parts. The first part is constituted by an introduction, theoretical framework, methodology, and a discussion of the methodology used in the thesis. The second part consists of the research study written according to the Scandinavian Journal of Medicine and Science in Sports. The third part contains appendices relevant to the thesis.

Part 1:

Theoretical background and methodology

Kristian Sørlie Lunde

University of Agder

Table of contents

1.0 Introduction

Soccer is a complex team sport that requires physical, tactical, and technical skills (Dolci et al., 2018). Furthermore, the nature of soccer is intermittent due to frequent changes in the speed and the direction of movement (Morgans et al., 2014; Chmura et al., 2017) and includes activities such as jumps, tackles, and sprints (Dolci et al., 2018). Changes in activities occur approximately every four to five seconds and around 1400 times during a match (Taylor et al., 2017). This diversity of activities and intensities requires energy provision from both the anaerobic and aerobic energy systems (Morgans et al., 2014; Chmura et al., 2017; Dolci et al., 2018).

The total distance covered during match play at the highest level has remained relatively constant in recent years (Barnes et al., 2014), whereas the frequency and distance covered by high-speed running and sprinting have substantially increased (Barnes et al., 2014). The growing importance of high-speed actions in modern soccer is further supported by Haugen et al. (2014a), stating that professional players have become slightly faster in the last fifteen years, with acceleration and maximum sprint capacity possibly distinguishing players from different standards of play. Furthermore, these high-speed actions are highly decisive for match outcome (Faude et al., 2012; Paul et al., 2015).

Various fitness tests are often used to evaluate players' physical abilities, strengths and weaknesses, optimize training programs and ultimately increase performance (Walker & Turner, 2009). Considering the importance of acceleration and maximum sprinting speed, linear sprint assessment is recommended for professional soccer players (Walker & Turner, 2009). However, to emphasize these test results, it is essential to know whether the test results are associated to the players' physical performance during match play.

Regarding players' physical performance during match play, the utilization of external workload monitoring tools has increased in professional soccer in recent years (Theodoropoulos et al., 2020). Currently, global navigation satellite system (GNSS) devices embedded with inertial movement units (IMU) is the most widely used technology to assess external workload variables (Beato et al., 2018). Such technology can measure locomotive activities in addition to capturing sport-specific movements such as accelerations, decelerations, change of direction, and accumulative load (Cummins et al., 2013; Chambers et al., 2015; Hennessy & Jeffreys, 2018), giving practitioners comprehensive insight into the external workload of players during training and match play. Thus, by comparing the results from lab-sprint performance and various match play variables, one may determine whether such tests reflects players' physical performance during match play.

Aim of research

The aim of this research study is to examine the relationship between lab-sprint performance and match physical performance in professional male soccer players.

Research question

Is there a meaningful relationship between 30-m sprint test data and match physical performance in professional male soccer players?

2.0 Theoretical background

2.1 Quantifying external workload

External load refers to the mechanical and locomotive actions performed by players (Gomez-Carmona et al., 2020) and is often assessed through variables such as speed, power, time-motion analysis, changes in speed, and changes of direction (Bourdon et al., 2017; Gomez-Carmona et al., 2020). Monitoring the load placed on players is considered fundamental to determining whether the athlete is adapting to the training program, understanding individual responses to training, determining fatigue and need for recovery, and thus reducing the risk of injury, illness, and overreaching (Bourdon et al., 2017).

Initially, assessment of players' external workload was achieved by manual video-based motion analysis techniques (Carling et al., 2008). However, these methods were time-consuming and restricted to only analyzing one player at a time (Carling et al., 2008). In the late 1990s, semi-automatic tracking systems such as AMISCO Pro and ProZone were established (Carling et al., 2008; Castellano et al., 2014). These systems can measure players' movements by a 10-25 frames per second sampling rate, resulting in approximately 4.5 million data points per match (Carling et al., 2008; Castellano et al., 2014). Semi-automatic tracking systems are valuable for identifying the physical, tactical, and technical activities during match play but require some development to accurately measure movements such as accelerations and direction changes (Castellano et al., 2014). Moreover, these systems are very expensive, and the cameras require a fixed installation, limiting the area of use to the clubs' home arena (Siti Azilah et al., 2019). Further limitations include variable capture areas, lighting conditions, occlusion between players, and the need for multiple cameras (Castellano et al., 2014). GNSS and local positioning systems (LPS) have been developed and frequently utilized to assess external workload in outdoor and indoor environments (Luteberget et al., 2018b). In 2015, the Fédération Internationale de Football Association (FIFA) allowed the use of GNSS in official soccer matches (Pons et al., 2019). These devices are portable, easy to transport to various locations, and recognized as a less time-consuming tracking system than video tracking systems (Beato et al., 2018). GNSS devices can provide real-time feedback due to the limited amount of time of post-processing analysis in addition to the lower amount of operator work required (Beato et al., 2018). Given these reasons, GNSS is the most widely used technology to assess external workload in team sports to date, although this method also has limitations (Beato et al., 2018). These limitations include the devices' sampling rate, positioning and fitting of devices, issues with signal reception, and data filtering methods (Hennessy & Jeffreys, 2018).

2.1.1 Global navigation satellite system

GNSS is a collective term that refers to all satellite navigation systems that provide geospatial positioning with global coverage (Jackson et al., 2018). This includes the Russian (GLONASS), American (GPS), European (Galileo), and Chinese (BeiDou) satellite systems, with only GLONASS and GPS being fully operational (Li et al., 2015).

GLONASS and GPS contain 24 satellites each, making GNSS devices capable of connecting to 48 satellites (Jackson et al., 2018). By doubling the number of satellites accessible during monitoring, the technology's resolution abilities may be improved and it is anticipated that GNSS devices will become more sensitive to changes in direction and speed than only using GPS devices (Jackson et al., 2018). Furthermore, GNSS consists of multiple revolving satellites that transfer unique signals enabling the GNSS devices to detect the precise location of the satellites (Hennessy & Jeffreys, 2018). The GNSS receiver calculates the distance to each satellite by the magnitude of time taken to receive the transmitted signal, determining the individuals' accurate location (Hennessy & Jeffreys, 2018). Thus, when the receiver links up with revolving satellites, GNSS receivers can give the receiver device's relatively exact positioning and speed (Hennessy & Jeffreys, 2018).

GNSS devices can quantify locomotive data such as total distance and speed but have limitations when applied to more sport-specific- and short-duration movements (Jackson et al., 2018; Luteberget et al., 2018a). Moreover, the sampling rate of the GNSS device determines the speed of the units' data-gathering (Cummins et al., 2013). During the first few years of using navigation satellite systems in sports, the devices were equipped with a sampling rate of 1Hertz (Hz) (Hennessey & Jeffreys, 2018). However, these devices did not provide sufficient validity or reliability (Hennessey & Jeffreys, 2018).

5Hz devices may accurately measure distance during linear walking (SEE 3.1%) and low speed running (SEE 2.9%) over moderate distances (50-60 m), but large underestimations occurred when measuring distance during 10-m (SEE 30.9%) and 20-m (SEE 17.0%) linear sprinting (Jennings et al., 2010; Scott et al., 2016). Additionally, neither striding nor sprinting achieved acceptable levels of validity during change of direction tasks (Jennings et al., 2010). Moderate validity was seen during linear running velocity measurements (CV <10%); however, limitations occurred when subjects performed sprints with standing or slow-moving starts (Scott et al., 2016). Moreover, Jennings et al. (2010) showed poor intraunit reliability in distance measurements during walking, jogging, striding, and sprinting <20 m, with 10-m sprint eliciting the weakest level of validity (CV 39.5%). However, acceptable intraunit reliability (CV 0.78-2.06%) occurred in velocity measurements during short-distance (0-30-m) sprinting (Scott et al., 2016). Poor interunit reliability (CV >10%) was seen during sprints with low initial speed and sprints involving accelerations with a low or high initial velocity, in addition to running that involved decelerations (Scott et al., 2016). Varley et al. (2012) found 10Hz devices to be more accurate than 5Hz devices when measuring instantaneous velocity during both acceleration, deceleration, and constant velocity. Moreover, 10Hz devices can measure distance during short and moderate distances with greater accuracy than 5Hz devices (Scott et al., 2016). Distance measurements during linear sprints over 15- and 30- m revealed 10.9 and 5.1% SEM, respectively (Scott et al. 2016). Additionally, Castellano et al. (2011) showed 10Hz devices to contain good intraunit (CV <5%) and interunit (CV 0.7 -1.3%) reliability in distance measurements during 15- and 30-m sprints. Despite 10Hz devices' ability to detect small changes in acceleration, the validity and interunit reliability of 10Hz devices may be acceleration-dependent (Akenhead et al., 2014). Especially acceleration movements >4 m/s^2 may compromise the reliability and validity of 10Hz devices (Akenhead et al., 2014). Thus, greater acceleration may lessen the validity and reliability of velocity measurements in 10Hz devices (Akenhead et al., 2014).

In summary, devices with sampling rates of 5Hz have limitations in distance measurements during short linear running, high intensity running, and velocity measures, while increasing the sampling rate beyond 10Hz does not appear to offer any additional benefits (Scott et al., 2016).

2.1.2 Inertial movement unit

IMU technologies consist of three sensor types; Accelerometer, gyroscope, and magnetometer (Ahmad et al., 2013; Luteberget et al., 2018a). The accelerometer measures mediolateral, vertical, and anterior-posterior movement planes (Krasnoff et al., 2008), the gyroscope measures angular rotation, and the magnetometer measures bearing magnetic direction (Ahmad et al., 2013). Then, the IMU combines the measurements from the accelerometer, gyroscope, and magnetometer to determine the acceleration of the body and body segments (Torres-Ronda et al., 2022). Due to recent developments in GNSS technology, most sport-specific tracking devices now include a triaxial inertial movement unit integrated with the GNSS device (Cummins et al., 2013; Chambers et al., 2015; Luteberget et al., 2018a).

As previously mentioned, GNSS devices struggle to measure sport-specific movements, whereas IMU devices have the ability to capture movements such as accelerations, decelerations, change of direction, and accumulative load (Cummins et al., 2013; Chambers et al., 2015; Hennessy & Jeffreys, 2018). Regarding accumulative load, PlayerLoad^{TM} is an IMU-derived variable that is frequently used in different sports contexts (Bredt et al., 2020). This variable is calculated from the square root of the sum of the squared instantaneous rate of change in acceleration in the anterior-posterior, mediolateral, and vertical movement planes (Montgomery et al., 2010; Boyd et al., 2011; Castillo et al., 2017) before being divided by 100 (Boyd et al., 2011). Considering reliability, PlayerLoad^{TM} has displayed moderate to high test-retest reliability and good interunit (CV 0.9%) reliability during simulated soccer matches and in field handball assessment, respectively (Barrett et al., 2015; Luteberget et al., 2018a). In addition to this, IMUs have generally exhibited good reliability and accuracy during controlled laboratory conditions and in sporting environments (Boyd et al., 2011; Luteberget et al., 2018a; Nicolella et al., 2018). Boyd et al. (2011) and Luteberget et al. (2018a) examined the reliability of IMU in Australian football and handball, respectively. Boyd et al. (2011) found IMUs to exhibit good intra (CV 0.91-1.05%) and inter reliability (CV 1.02-1.10%) during laboratory testing, in addition to good interunit reliability (CV 1.94%) during field testing. Luteberget et al. (2018a) revealed good interunit reliability in well-controlled laboratory tasks (CV 3.1%), with the reliability slightly decreasing during more complex tasks (CV 4.4-6.7%). Moreover, total counts from the inertial movement analysis demonstrated good interunit reliability (CV 1.8%) during field assessment but the reliability decreased (CV 2.9-5.6%) when classified into intensity bands (Luteberget et al., 2018a).

Lastly, Nicolella et al. (2018) found IMUs to provide exceptional intraunit reliability (CV 0.01- <3.0%) during controlled laboratory testing. However, interunit reliability was highly variable, with CV% values ranging from trivial to extreme (Nicolella et al., 2018). Considering this, ensuring that players use the same device every time may be the safest option concerning reliability.

2.1.3 Summary

Sports tracking technology has developed in line with the increased importance of player monitoring. Monitoring players' external load is an important factor in understanding adaption to training and providing sufficient recovery for players (Bourdon et al., 2017). Today, 10Hz GNSS devices embedded with IMUs appear to be the most convenient, reliable, and accurate tracking equipment to monitor external workload variables in soccer, as these devices have exhibited good reliability and accuracy during field and laboratory assessments.

2.2 Physical demands in soccer

LPS, GPS, and GNSS-derived data have found professional players across a variety of countries and leagues to cover an average distance of ~10 500 ± 800 m per match, dependent on playing position (Varley et al., 2014; Wehbe et al., 2014; Ingebrigtsen et al., 2015; Dalen et al., 2016; Abbott et al., 2018b; Modric et al., 2019; Mitrotasios et al., 2021; Reynolds et al., 2021). Regarding positional differences, central midfielders covered the greatest distance (~11 400 ± 700 m), followed by wide midfielders (~11 100 ± 600 m), full-backs (~10 900 ± 600 m), attackers (~10 200 ± 600 m), and central defenders (~9900 ± 500 m), respectively (Ingebrigtsen et al., 2015; Dalen et al., 2016; Abbott et al., 2018b; Modric et al., 2019; Mitrotasios et al., 2021). In terms of match play intensity, 79% of the total distance was covered by low-intensity activities (<14.4 km/h) such as walking and jogging (Ingebrigtsen et al., 2015; Dalen et al., 2016; Modric et al., 2019; Mitrotasios et al., 2021). This aligns with Casajus's (2001) suggestion that aerobic metabolism provides 70-80% of the energy provision during soccer matches. However, the development of aerobic capacity has stagnated in recent years, and soccer-related research has shifted focus towards anaerobic demands (Haugen et al., 2014a).

2.2.1 High-speed running and sprinting

Several authors have examined the characteristics of high-speed running and sprinting in soccer, utilizing various measuring methods and speed thresholds. The sprinting speed threshold is often set as >25.2 km/h (Ingebrigtsen et al., 2015; Modric et al., 2019; Mitrotasios et al., 2021; Reynolds et al., 2021), although thresholds of >24 km/h (Andrzejewski et al., 2013), >23 km/h (Di salvo et al., 2007; Lago-Peñas et al., 2009), >22 km/h (Osgnach et al., 2010) and >19 km/h (Vigne et al., 2010) also has been used. As a result of the utilization of different speed thresholds, comparisons of activity profile research may become challenging (Sweeting et al., 2017). In the section below, high-speed runs and sprints will be characterized as 19.8-25.2 km/h and >25.2 km/h, respectively, if not otherwise stated.

Regarding high-speed running, Barnes et al. (2014) found that the frequency and distance covered by high-speed running increased by ~ 50 and ~ 30%, respectively, during seven seasons in the English top division. Moreover, research utilizing LPS, GPS, and GNSS data has found professional players to cover an average of 662 ± 231 m during high intensity running, corresponding to 6.2% of the total distance covered during a match (Ingebrigtsen et al., 2015; Dalen et al., 2016; Modric et al., 2019; Mitrotasios et al., 2021; Reynolds et al., 2021). The greatest distance covered by high-speed running was performed by wide midfielders (856 ± 176 m), followed by full-backs (841 ± 213 m), attackers (635 ± 158 m), central midfielders (625 ± 212 m), and central defenders (405 ± 108 m), respectively (Ingebrigtsen et al., 2015; Dalen et al., 2016; Modric et al., 2019; Mitrotasios et al., 2021).

Turning now to sprinting, the research from Barnes et al. (2014) revealed that the frequency and distance of sprinting actions (>25.1 km/h) increased by ~ 85 and ~35%, respectively, during the same period as previously mentioned. In addition to the findings of Barnes et al. (2014), the importance of sprinting is illustrated in Faude et al. (2012), where the authors analyzed goal scoring patterns in the German top division during the second half of the 07/08 season. The results revealed that the most frequent powerful action for the goal scoring and assisting player were linear sprints (45 and 38%, respectively).

In terms of sprint characteristics during match play, research suggests that professional players cover an average of 157 ± 100 m during sprinting, corresponding to 1.5% of the total distance covered during a match (Varley et al., 2014; Ingebrigtsen et al., 2015; Dalen et., 2016; Modric et al., 2019; Mitrotasios et al., 2021; Reynolds et al., 2021). Concerning positional differences, full-backs covered the greatest sprinting distance (272 ± 104 m), followed by wide midfielders (238 ± 81 m), attackers (184 ± 85 m), central midfielders (128 ± 68 m), and central defenders (95 ± 51 m), respectively (Ingebrigtsen et al., 2015; Dalen et al., 2016; Modric et al., 2019; Mitrotasios et al., 2021).

It is important to mention that match running performance can be influenced by various factors, including match location, opposition standard, match importance, tactical factors, match status (win, draw, lose), and pre-match recovery status (Lago-Peñas et al., 2012; Paul et al., 2015). For instance, differences in high-speed running (Modric et al., 2020) and sprinting (Vilamitjana et al., 2021) characteristics have been observed using different playing formations. Additionally, Aquino et al. (2020) found players to perform greater distances during high-speed running (>19 km/h) in home matches compared to away matches, against weaker opposition compared to stronger opposition, and in matches where the team won.

In summary, the frequency and distance covered by high-speed running and sprinting have increased in recent years and are becoming increasingly important in modern soccer. The demands for high-speed running and sprinting are position-specific, with wide midfielders and full-backs required to perform the greatest amounts of these actions.

2.2.2 Accelerations, decelerations, and change of direction

The term acceleration refers to the rate of change in velocity that enables the player to reach maximal speed in the shortest amount of time (Little & Williams, 2005). During team sports such as soccer, a large number of high-speed actions are short in duration and commenced from a low intensity, which places great demands on players' ability to accelerate (Sweeting et al., 2017). Furthermore, the importance of accelerations is illustrated in Varley & Aughey (2013), where the authors found professional soccer players to perform ~ eight times more accelerations than sprints during a match. Contrary to accelerations, deceleration refers to the players' ability to reduce velocity (Sweeting et al., 2017). Furthermore, players are required to perform decelerations after every sprinting action to slow the body's center of mass (Hewit et al., 2011). As decelerations often occur as a response to other players' movements, soccer players must decelerate over various distances, time, and from multiple velocities (Hewit et al., 2011). Additionally, the ability to decelerate is a critical component for effectively performing changes of direction (Kovacs et al., 2008; Sweeting et al., 2017).

In the case of acceleration and deceleration profiles during match play, IMU-derived data have shown that professional male soccer players perform 82 ± 16 accelerations (>2 m/s^2) and 76 ± 16 decelerations (>2 m/s^2) during match play (Ingebrigtsen et al., 2015; Dalen et al., 2016; Baptista et al., 2018; Vigh-Larsen et al., 2018; Pons et al., 2019).

In addition to these actions, the ability to change direction during sprinting is a performance determinant in soccer and often occurs as a reaction to a stimulus (Sheppard & Young, 2006). Video analyses from Bloomfield et al. (2007) found that players in the English top division performed 726 ± 203 turns per match. Most of these turns were performed at 0-90° left (303.2 ± 99.3) and right (305.8 ± 104.7). Additionally, IMU data from Granero-Gil et al. (2020) found players from the Russian top division to perform 471± 175 changes of direction (classified as curvilinear locomotion > 800 milliseconds) during a match.

In summary, accelerations, decelerations, and changes of direction are crucial elements of soccer match play and are regarded as important determinators of match play performance. Based on professional soccer match play data, players are required to frequently perform intense accelerations, decelerations, and changes of direction during a match.

2.2.3 Summary

High-speed actions constitute a small portion of match play but are highly decisive for match outcome (Faude et al., 2012; Ingebrigtsen et al., 2015; Dalen et al., 2016; Modric et al., 2019; Mitrotasios et al., 2021). Despite only constituting a small portion of match play, players are required to regularly perform high-speed runs, sprints, accelerations, decelerations, and direction changes. The frequency of high-speed actions is position-specific, making it reasonable to believe that different playing positions require different physical demands. Additionally, the frequency of high-speed actions appears to be influenced by various contextual, situational, and tactical variables that vary from match to match (Lago-Peñas et al., 2012; Paul et al., 2015).

2.3 Sprint-test results in professional soccer

Sprint data from Haugen et al. (2014a) suggests that professional players have become slightly faster in the last fifteen years. Moreover, players’ sprinting abilities peaks between the age of 20-28, while slowly decreasing in the years after (Haugen et al., 2014a). Additionally, acceleration and maximum sprint capacity may distinguish players from different standards of play, with players from the top European leagues being slightly faster than players from lower-ranked leagues (Haugen et al., 2014a). There are also tendencies toward positional differences in sprinting velocities, with data indicating that attackers achieve the fastest sprinting times (Sporis et al., 2009; Haugen et al., 2013).

Sprint data from the Norwegian Olympic Training Center, including 628 elite male soccer players, reveals that the difference between the 75th and 25th percentile is 0.13 seconds, with the fastest quartile being >1 m faster than the slowest quartile during a 20-m sprint (Haugen et al., 2014a). Additionally, the difference between the fastest players (10th percentile) and slowest players (90th percentile) is equivalent to >2 m during a 20- m sprint (Haugen et al., 2014a). Additionally, 10% of fastest players sprint 1 m longer than 10% of slowest players per second during peak sprinting (Haugen et al., 2014a). During a match, a 30-50 cm (~0.04-0.06 seconds in a 20-m sprint) difference is assumed to be enough to win the ball in front of the opposition in a one versus one duel (Haugen et al., 2014a), illustrating the importance of acceleration and maximal velocity in professional soccer.

Several authors have examined the sprinting performance of professional soccer players in various distances, leagues, nations, and competitions. However, it is challenging to compare research on soccer sprint test results due to differences in study designs, measuring methods, timing equipment, environmental factors, surface, and time of the competitive season. Haugen et al. (2012) observed that the starting method could produce differences up to 0.69 seconds in 40-m sprint time. Furthermore, the authors detected 0.42 seconds faster sprint times during 40-m starts with plate triggering compared to starting by breaking photocell beams. Additionally, the level of flying start also influences sprinting times. Haugen et al. (2015) observed that increasing the distance from the starting line from 0.5-1 m elicited an 0.06-0.08

second decrease in sprinting time over 20 m. Haugen et al. (2014b) detected absolute time differences between single and dual beamed photocells of 0.05-0.06 seconds during a 20-m sprint. Moreover, Cronin & Templeton (2008) found the height of the timing lights to affect sprint results by a mean of 0.07 seconds during 10- and 20-m sprints. In terms of optimal photocell height, Haugen & Buccheit (2016) suggests that all types of photocells should at least be placed above hip height to reduce the risk of the lower limb accidentally breaking the photocell beam before the subject begin sprinting. Moreover, environmental factors and surfaces may also alter sprinting performance (Haugen & Buccheit, 2016). The importance of sprinting surface is illustrated in Brechue et al. (2005), where the athletes experienced a 0.12-0.15 seconds decrease in 40-yard time by sprinting on a rubberized track versus natural grass.

Table 1 summarizes a selection of studies examining sprinting times in professional soccer players. In summary, eight articles examined sprinting performance at 5-m with results ranging from 0.84-1.44 seconds. Furthermore, 10-m performance was assessed in 17 articles and ranged from 1.51-2.27 seconds. Ten articles observed 20-m performance, with sprint times ranging from 2.75-3.38 seconds. Lastly, 30-m performance was examined in 12 articles, with results ranging from 3.89-4.41 seconds.

Table 1: *Literature overview of sprint test results in male professional soccer.*

Article	**Playing level**	**Testing period**	**Method**	**Surface**	**Location**	**Distance from starting line (m)**	**5-m**	**10-m**	**20-m**	**30-m**	**Comments**
Dunbar & Power (1995)	English top division	In season	Electronic timing - NR	Sports hall	Indoor	NR				3.94 s	Two trials – Fastest used
Cometti et al. (2001)	French top division	In season	Infrared photocells - NR	Soccer field	NR	NR		1.80 s		4.22 s	Visual que-three trials-fastest used
Wisløff et al. (2004)	Norwegian top division	NR	Photocells - Single	Parquet	Indoor	0.3		1.82 s	3.00 s	4.00 s	Two trials-fastest used
Dunbar & Treasure (2005)	English top division	In season	Electronic timing - NR	Artificial turf	Indoor	NR		1.73 s	2.98 s		NR
Little & Williams (2005)	English first and second division	In season	Photocells - Single	Synthetic	Indoor	NR		1.83 s			Two trials-fastest used
Jullien et al. (2008)	Young professionals in France	Pre-season	Photocells - NR	NR	Outdoor	NR		1.85 s			One trial

Rønnestad et al. (2008)	Norwegian top division	Pre-season	Photocells - NR	Hard even surface	Indoor	0.5		1.78 s			Three to four trials-fastest used
Taskin (2008)	Turkish league system	In season	Photocells - NR	NR	Outdoor	NR				4.26 s	Signal – two trials-fastest used
Gorostiaga et al. (2009)	Spanish top division	In season	Photocells - NR	Court	Indoor	0.5	0.99 s				Three trials-fastest used
Sporis et al. (2009)	Croatian top division	Pre-season	Telemetric photocells–NR	NR	Indoor	NR	1.44 s	2.27 s	3.38 s		Three trials-mean used
Wong et al. (2010)	Top division in Hong Kong	Pre-season	Photocells - Single	Soccer field	Outdoor	0.5		1.82 s		4.41 s	Three trials-fastest used
Cotte & Chatard (2011)	English top division	Pre-season	Photocells - Single	Artificial turf	Indoor	0		1.69 s	2.94 s	4.10 s	Two trials-fastest used
Helgerud et al. (2011)	Norwegian top division	Pre-season	Photocells - Single	Parquet	Indoor	0		1.87 s	3.13 s		Two trials-fastest used
Haugen et al. (2013)	Norwegian national team	NR	Photocells +Start pad- Dual	Rubber	Indoor	0		1.51 s	2.75 s	3.89 s	UDIP-fastest used
Silva et al. (2013)	Portuguese top division	In season	Photocells - Single	NR	Indoor	0.3	1.02 s			4.20 s	Two trials-fastest used

Edholm et al. (2014)	Swedish top division	NR	Infrared photocells – Dual	Grass	Outdoor	0.5		1.88 s			Two trials-fastest used
Requena et al. (2016)	Spanish top division	In season	Photocells - Single	NR	NR	0.3		1.82 s		4.21 s	Four trials-fastest used
Drozd et al. (2017)	Polish top division	In season	Photocells - NR	NR	Indoor	NR	1.07 s		3.08 s	4.21 s	NR-fastest used
Krommes et al. (2017)	Danish top division	Winter break	Photocells - NR	All-weather track	Indoor	NR	0.84 s	1.60 s		4.04 s	Three trials-fastest used
Baumgart et al. (2018)	German top division	NR	Photocells - Dual	Artificial turf	NR	1	1.11 s	1.84 s	3.09 s	4.25 s	Three trials-mean of two fastest used
Gil et al. (2018)	State and national championship players in Brazil	Pre-season	Photocells – Single corrected	Running track	Indoor	0.3	1.06 s	1.77 s	3.02 s		Three trials-fastest used
McMorrow et al. (2019)	Irish top division	In season	Photocells – Single corrected	Grass	Outdoor	0.3	1.18 s	1.93 s	3.19 s		Parallel start-three trials-fastest used

UDIP=Until decline in performance. NR=Not reported. (M)=meters. S=Seconds.

2.4 Determinants of sprinting ability

Sprinting velocity is ultimately determined by stride length and stride rate (Mero et al., 1992; Ross et al., 2001) but is influenced by numerous interconnected factors (Loturco et al., 2019; Ross et al., 2001). Furthermore, sprinting movements require the hip, knee, and ankle joints to accelerate the body horizontally at the same time as counteracting the force of gravity in the vertical direction (Delecluse, 1997). Delecluse (1997) separates sprinting into three phases: Initial acceleration (0-10 m), transition phase (10-36 m), and maximum running speed (36-100 m). Similarly, Mero et al. (1992) suggest that professional sprinters reach top speed in 30-50 m, with more than 80% of top speed achieved after 20 m (Young et al., 2001). According to data from Di Salvo et al. (2009), Bradley et al. (2010), and Ingebrigtsen et al. (2015), the mean distance per sprint is 7-12.8 m. Based on this, the ability to accelerate appears to be the single most crucial sprinting attribute in soccer. However, soccer sprints are often initiated from a moving start (Rumpf et al., 2016), illustrated by the findings of Di salvo et al. (2010), where the researchers found 77% of all sprints to be performed from a commenced high-speed run. Considering that most sprints are commenced from a high-speed run, players are able to reach near-maximum speed more frequently than the parameters of time and distance predict (Little & Williams, 2005; Rumpf et al., 2016).

Sprinting ability in soccer further deviates from general sprinting in certain areas, especially by the amount of multidirectional and curvilinear movements performed during a match (Ade et al., 2016; Fitzpatrick et al., 2019; Caldbeck, 2019, p. 158). In addition to the changes of direction mentioned in 2.2.2, soccer players often perform arc runs (moving in a semi-circular direction) and swerves (changing direction without rotating the body) (Ade et al., 2016). Furthermore, soccer players are regularly required to perform sprinting movements with some degrees of curvature (Loturco et al., 2020). Research from Caldbeck (2019, p. 159) found that 83-88% of maximal sprint efforts in soccer could be characterized as curvilinear. Additionally, Fitzpatrick et al. (2019) revealed that the average sprinting angle in soccer is approximately 5º but may reach an angle of up to 30º. Moreover, curvilinear sprints involve different biomechanical requirements than straight sprinting (Caldbeck, 2019, p. 58).

For instance, Churchill et al. (2015; 2016) observed reduced step frequency and step length, reduced force production, and greater demand for the inside leg to generate inward impulse during curvilinear sprinting, resulting in reduced velocity. However, several of the same determinants of sprinting ability exist between soccer sprinting and general sprinting.

The stride commonly consists of four different phases, referred to as the running gait cycle (Kapri et al., 2021). The first phase (the early stance phase) starts when the players' foot makes initial contact with the surface, finishes at the mid-stance phase, and is estimated at 0-15% of the cycle (Howard et al., 2018). The second phase (the late stance phase) starts in the mid-stance phase and finishes as the toe leaves the surface (toe-off) and is estimated at 15-30% of the cycle (Novacheck, 1998; Howard et al., 2018). The third phase (the early and middle swing phase) is initiated at the toe-off phase, finishes approximately 2/3 through the swing phase, and is estimated at 30-77% of the running gait cycle (Howard et al., 2018). The fourth phase (the late swing phase) starts approximately two-thirds through the swing phase, finishes as the foot again makes initial contact, and is estimated at 77-100% of the cycle (Howard et al., 2018). In terms of muscle involvement, this differs throughout the running gait cycle (Novacheck, 1998; Howard et al., 2018). The hamstrings (biceps femoris, semitendinosus, and semimembranosus), rectus femoris, vastus lateralis, gluteus maximus, gastrocnemius, soleus, and tibialis anterior are involved in the first phase (Chumanov et al., 2011; Howard et al., 2018), while the soleus, vastus lateralis, and hamstrings are the main contributors in the second phase (Howard et al., 2018). The early and middle swing phase mainly consists of muscle actions from the rectus femoris and tibialis anterior (Novacheck, 1998; Chumanov et al., 2011). Lastly, both the tibialis anterior, rectus femoris, hamstrings, vastus lateralis, gluteus maximus, gastrocnemius, and soleus are involved in the fourth phase (Novacheck, 1998; Chumanov et al., 2011; Howard et al., 2018).

Muscle involvement during sprinting varies between the initial acceleration phase and the maximal speed phase due to shifts in the lean of the body (Delecluse, 1997). Two fundamental movements, consisting of 1) Forward rotation of the body, and 2) extension of the lower limb joints during contact with the surface, occur during the first steps of the initial acceleration phase (Delecluse, 1997). During this phase, the majority of the force is derived from contractions from the quadriceps femoris and gluteus maximus (Delecluse, 1997). Furthermore, the athletes shift to an upright position during the maximal speed phase, which makes their velocity largely dependent on the velocity of the swing back of the legs (Delecluse, 1997). Moreover, forward propulsion in this phase is mainly decided by actions of the biceps femoris, gluteus maximus, and adductor magnus – with the biceps femoris being the main contributor to speed development (Delecluse, 1997). During sprinting, the contact time typically ranges from 70-90 milliseconds (Taylor & Beneke, 2012), which places great demands on the players' ability to perform fast contractions with high force (power). Regarding this, power is defined as $\frac{\text{Force} \cdot \text{distance}}{\text{Time}}$ (Raastad et al., 2010, p. 225), and plays a major part in stride length and stride rate (Ross et al., 2001). Furthermore, maximal power represents the highest instantaneous power during a single movement performed with the intention of producing maximal velocity during take-off, release, or impact and includes movements such as sprinting, jumping, and changes of direction (Cormie et al., 2011a). Generally, power production is essential in all sprinting types but seems especially important in maximum speed sprinting due to the short contact time in this phase (Young et al., 2001).

Multiple aspects influence power production, including muscle mechanics, muscle environment, morphological and neural factors (Cormie et al., 2011a). The force-velocity relationship is especially important, as a reverse relationship exists between force and velocity during concentric muscle contraction (Cormie et al., 2011a). Increased velocity of concentric muscle action will cause the muscle to produce less force during contraction, while increased force production will reduce the velocity of the muscle action (Cormie et al., 2011a). This relationship is described as the Hill curve and is illustrated in figure 1.

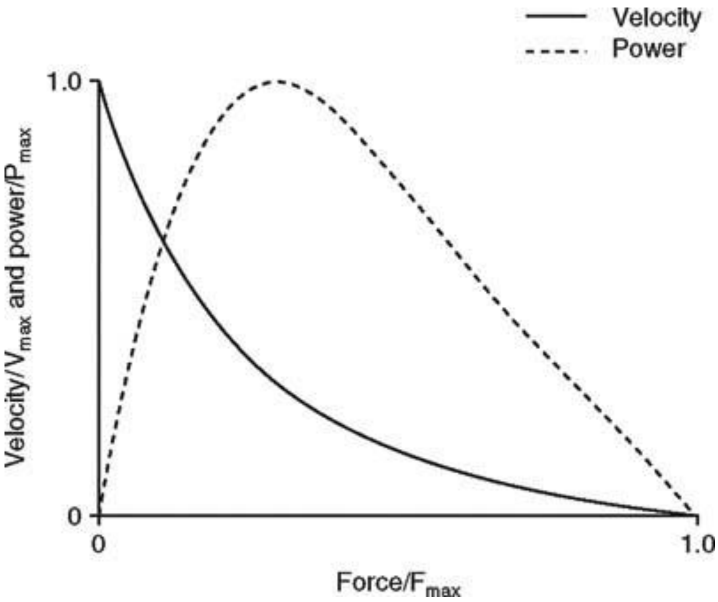


Figure 1: *The inverse relationship between force and velocity during concentric muscle contraction (Adapted from Cormie et al., 2011a).*

Additionally, morphological determinants of power production include muscle fiber type, muscle length, and cross-sectional area (Raastad et al., 2010, p. 227). Muscle fiber types are divided into type I, type IIA and IIX, and it will be beneficial to possess a majority of type II fibers as these fibers have greater potential to produce power per unit of cross-sectional area (Cormie et al., 2011a). The muscles' cross-sectional area is strongly correlated with power production, and an increase in the cross-sectional area leads to greater power production ability (Raastad et al., 2010, p. 227). Furthermore, maximal power is highly dependent on the nervous systems' ability to appropriately activate the involved muscles (Cormie et al., 2011a). The force produced by a muscle is associated with the total and type of motor units recruited (Cormie et al., 2011a). Moreover, the firing frequency, which refers to the rate of neural impulses transferred from α-motoneurons to muscle fibers, is influential on maximal power production due to being able to enhance the magnitude of force development during contractions, in addition to influencing the rate of force development (Cormie et al., 2011a). There are ultimately three key elements to consider when aiming to maximize maximal muscle power: Maximal muscular strength, the ability to express high forces in short periods, and the ability to express high forces when the velocity of shortening increases (Haff & Nimphius, 2012). Strong interplay exists between these factors, with maximal muscle strength being the main factor in power production (Haff & Nimphius, 2012). Moreover, the fundamental relationship between muscular strength and power development leads to the assertion that an athlete cannot produce high levels of power without being relatively strong (Cormie et al., 2011b). Several researchers have observed moderate (McBride et al., 2009; Chaouachi et al., 2009) and strong (Wisløff et al., 2004) relationships between maximal muscle strength and performance in various sprinting distances. Furthermore, several researchers (Hammami et al., 2018; Chelly et al., 2009; Styles et al., 2016) have reported significant improvements in sprinting variables in soccer players following resistance training interventions (70-90% 1RM). Thus, it is reasonable to believe that maximal muscle strength and resistance training are essential for developing sprinting ability in soccer players.

2.4.1 Summary

The determinants of sprinting ability in soccer deviate to a certain degree from those of general sprinting, albeit sharing several determining factors. The greatest difference between soccer sprinting and general sprinting is that the average sprinting distance in soccer is short, in addition to the requirements of performing frequent multidirectional and curvilinear sprinting actions during a soccer match, which involve different biomechanical requirements than those found in linear sprinting (Churchill et al., 2015;2016, Caldbeck, 2019, p. 58). Furthermore, maximal muscular power is a major determinant of sprinting ability (Ross et al., 2001; Cormie et al., 2011a), especially during maximum speed sprinting due to the short contact time (Young et al., 2001). A variety of factors influence an individuals' power production, including muscle mechanics, muscle environment, morphological and neural factors (Cormie et al., 2011a). Ultimately, the ability to express high forces when the velocity of shortening increases, rate of force development, and especially maximal muscle strength are the greatest determinants of maximal muscle power (Cormie et al., 2011b; Haff & Nimphius, 2012).

3.0 Methods

The data presented in this research study was part of a larger research project that examined the effects of objective versus subjective autoregulated resistance training in professional soccer players. The project started with pre-tests in the fall of 2021, followed by a 10 -week intervention period consisting of 11 resistance training sessions, and ended with post-tests in the winter of 2021. During the intervention period, the club played 13 matches.

3.1 Design

This research study used a cross-sectional research design to examine the relationship between lab-test performance and different match play variables. The lab-test data were collected during pre-testing performed on September 6, 2021, while match data were collected from seven matches from September 11 to October 2. The data collection period included four home matches and three away matches, resulting in three wins, one draw, and three losses. 108 observations were made during these matches, with an average of 15.4 ± 0.5 players participating in each match. The full project schedule, including the data collection period of this research study, is illustrated in figure 2.

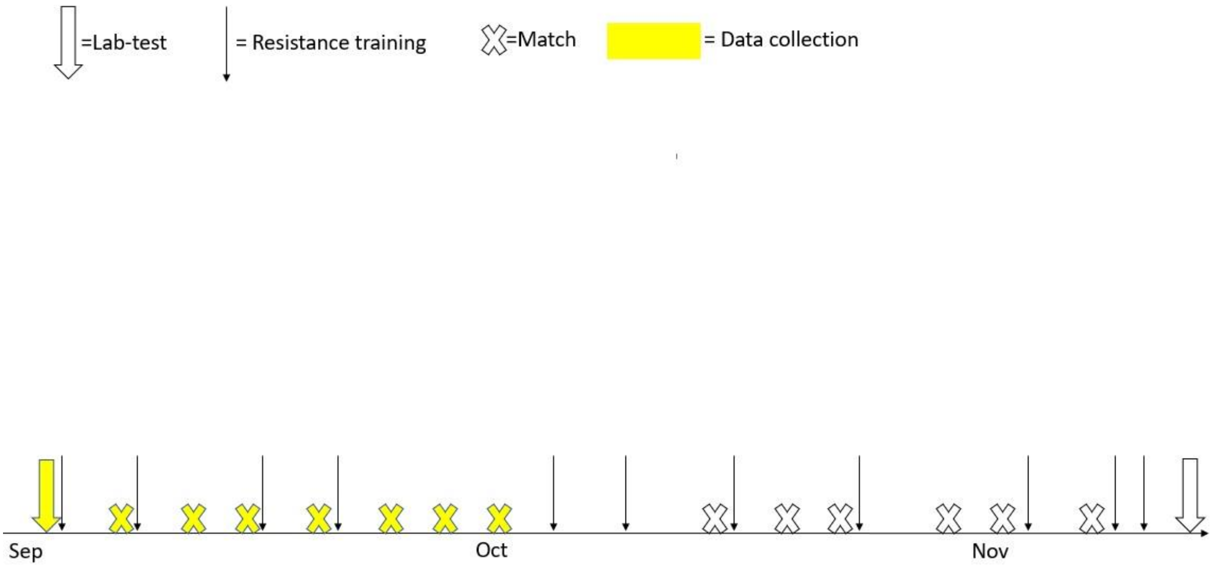


***Figure 2**: Project schedule.*

3.2 Subjects

Twenty-six male professional soccer players belonging to the same club competing at the second-highest playing level in Norway were invited to participate in this research study. To be included in the research study, the subjects had to meet the following inclusion criteria: Be outfield players, perform the 30-m sprint pre-test, and provide >60 minutes of GNSS data in a minimum of four matches during the data collection period. The subjects were excluded if they were goalkeepers, did not sprint during pre-testing, were injured, or did not provide the required GNSS data during the data collection period. Of the invited subjects, five players were excluded from sprint testing due to being goalkeepers (n=3), injured (n=1), and on loan (n=1). Of the remaining 21 players, 10 players were excluded from the analysis due to not reaching the playing time threshold during the data collection period. Thus, 11 players (25.5 ± 3.4 years, 183.8 ± 5 cm, and 78.3 ± 4.9 kg) playing as defenders (n=5), midfielders (n=4), and attackers (=2) met the inclusion criteria and were included in the analysis. A total of 55 observations were analyzed during the data collection period. The included subjects played an average of 5 ± 1 matches >60 minutes with an average playing time of 82.8 ± 6.8 minutes per match. Regarding the resistance training, four and five players were enrolled in the objective and subjective autoregulation groups, respectively. The remaining two players did not participate in the resistance training intervention. During the data collection period, the players performed 3.7 ± 0.9 resistance training sessions, which consisted of 3.6 ± 0.7 light/normal sessions and 0.3 ± 0.7 hard sessions.

3.3 Ethical considerations

Approval was obtained from the Norwegian center for research data (NSD) and the Faculty Ethics Community (FEK) prior to starting the project. Participants received oral and written information regarding the methods and aims of the project and the potential benefits and risks associated with participating. All subjects were required to provide written consent prior to commencing the project to be included. Participation was voluntary, and the subjects had the right to withdraw from the project at any time without providing any further explanation or consequences. All information regarding the subjects was kept confidential and only club representatives, in addition to master students and supervisors associated with the project, had access to the information. All personal information was anonymized by ID numbers and only decryptable by a decryption key stored locally in a safe at the Institute of Sport Science and Physical Education offices at the University of Agder, Kristiansand. The data were preserved according to the Norwegian center of research data (NSD) guidelines, and the research study was completed in accordance with the declaration of Helsinki.

3.4 Lab-Test procedures

Testing was performed at the lab facilities of the University of Agder, Kristiansand, Norway, during the international break in the fall of 2021. The players arrived fully rested to testing, having had two days off without any training/match load. The players arrived at the testing facility one by one and signed a written consent upon arrival. As previously stated, the sprint performance assessment was part of a larger research project that included other masters' students and several other physical tests. Based on the relevance to the research question of this research study, the section below describes the sprint test in detail, whereas the other physical tests are only briefly mentioned.

The full test protocol consisted of dual-energy x-ray absorptiometry, musculoskeletal ultrasonography, 30-m sprint, countermovement jump, and leg press. The dual-energy x-ray absorptiometry was performed separately, approximately one week prior to the other tests. Thus, the subjects began the test day by ultrasound scanning. After that, the players were instructed to perform a 10-minute self-paced treadmill warm-up to prepare for sprinting. The players were immediately forwarded to countermovement jump-warm up following their last sprint trial. Then, following countermovement jump assessment, the players were sent directly to leg press-warm up. Each player spent approximately 1.5 hours performing the full test protocol.

3.4.1 Sprint test

30-m sprint was performed on an indoor sports floor with a synthetic surface. Seven pairs of dual beamed photocells (MuscleLab 20, version 10.201.93.0, Ergotest, Porsgrunn, Norway) were placed at 0-, 5-, 10-, 15-, 20-, 25-, and 30-m, 1.6 m apart, and at 120 cm height. The first set of photocells and reflectors were placed at the starting line (at the same place as the subjects placed their front foot), and the recording was initiated as soon as the subjects began moving forward. The sprint test setup is illustrated in figure 3.

Prior to sprinting, the players were instructed to perform a minimum of two sub-maximal, high-speed runs with gradually increasing intensity. Following these initial sub-maximal, high-speed runs, the players were asked if they felt ready to start sprinting. If they did not feel ready to start sprinting, they were encouraged to perform one or two more runs. Four minutes after the final submaximal high-speed run, the players began the first 30-m sprint. The sprint test began from a stand-still, upright position with a staggered stance with their preferred foot at the starting line and the other foot placed further back. The distance from the front to the rear foot was self-determined based on individual preferences. The players were allowed to initiate the start by doing one small countermovement as long as both feet remained in full contact with the surface. Then, the players were instructed to sprint maximally throughout the 30-m test. The subjects initially performed three sprints but were encouraged to perform one additional run if they recorded their best sprint time on the third trial. This protocol was maintained until the athlete failed to improve his time or was fatigued. Four-minute rest intervals were maintained between all trials. The testing personnel provided verbal encouragement throughout the sprints to ensure maximal effort. The participants' single best sprinting time was collected and used in the data analysis.

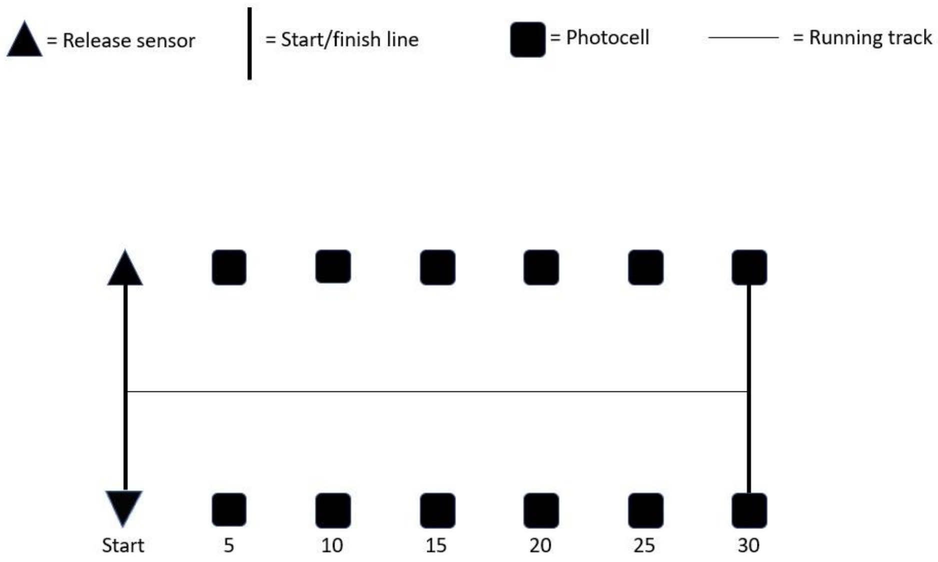


Figure 3: *Illustration of the sprint test.*

3.5 Player monitoring / Match performance

Catapult Vector S7 (Catapult Sports, Melbourne, Australia) was used to assess external workload during matches. Vector S7 is a GNSS device with a 10Hz sampling rate embedded with an inertial movement unit (Souza, 2021a). The IMU contains an accelerometer, gyroscope, and magnetometer, all sampling at 100Hz (Souza, 2021a). The Vector S7 units are 15,9 mm thick, 81 mm long, 43,5 mm wide, and weigh 53 grams (Souza, 2021b). The GNSS device was placed in the garment pocket of a fitted vest, located between the players' scapulae with the players wearing the same vests and units to ensure interunit reliability during the data collection period.

3.6 Data processing

The participants' single best 30-m sprinting time and the associated timings at 5-,10-,15-,20-, and 25-m were collected and used in the data analysis, while the variables derived from the GNSS device included playing time (minutes), total duration (minutes), total distance covered, meters covered per minute, distance covered by high-speed running (19.8-25.2 km/h), distance covered by sprinting (>25.2 km/h), and maximal velocity (meters per second, m/s). The GNSS-derived match data were uploaded in the manufacturer's digital software OpenField (version 2.5.0) before being downloaded and organized in Microsoft Excel version 2203 (Microsoft Corporation, Redmon, WA, USA).

3.7 Statistics

Lab-sprint results and GNSS variables were calculated using Microsoft Excel version 2203 (Microsoft Corporation, Redmon, WA, USA) and presented as mean ± SD. To examine the relationship between the lab-sprint results and GNSS variables, A Bayesian correlation analysis with non-parametric Kendall's Tau-b correlation coefficients was conducted in JASP version 0.16.1.0. The results were reported as Kendall's Tau-b and Bayes factor (Bf_{10}). The magnitude of the Kendall’s Tau-b correlation coefficient is classified as 0.1 (small), 0.3 (moderate), 0.5 (large), 0.7 (very large) and 0.9 (extremely large), in accordance with the suggestions of Hopkins et al. (2009). The BF_{10} value was interpreted according to the recommendations of Quintana & Williams (2018) and Schmalz et al. (2021) and is illustrated in figure 3.

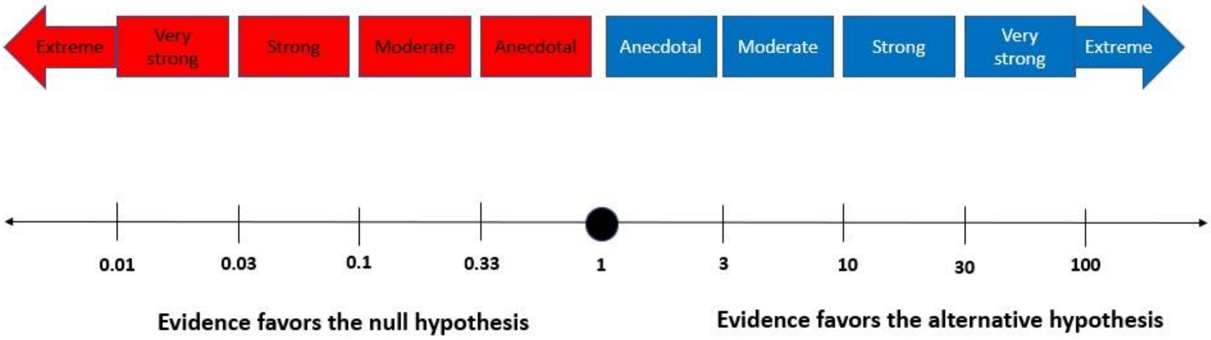


***Figure 4**: Interpretation of the Bayes factor. Adapted from Quintana & Williams (2018).*

4.0 Discussion of methodology

4.1 Research design

A cross-sectional design was used to examine the correlation between lab-sprint performance and match play variables. Furthermore, correlational research is used when examining the relationship between two or more variables that cannot be manipulated (Polit & Beck, 2018, p. 146) which makes this a suitable approach for answering the research question of this research study. However, observational designs are generally weaker than experimental designs, as the lack of control from the investigator can increase the risk of confounding factors and biased outcomes, which may compromise the validity of the research (Polit & Beck, 2018, p. 146; Hess & Abd-Elsayed, 2019). Further limitations of observational designs concern their limited value in providing causal associations (Boyko, 2013; Polit & Beck, 2018, p. 146). Even if the association is strong, the sheer existence of a relationship between variables is insufficient to prove that one variable caused the other (Polit & Beck, 2018, p. 146). Thus, the results of this research study should be interpreted with caution.

4.2 Statistical analysis

Regarding statistical analysis, Kendall's Tau-b and Bayes factor were used to examine the relationship between variables. The non-parametric Kendall's Tau-b was utilized due to the recommendations of using non-parametric tests in small sample sizes (Dwivedi et al., 2017) and the challenges of obtaining normal distributions in small datasets. Moreover, the Bayes factor is a popular method in the Bayesian approach (Quintana & Williams, 2018) and is considered the gold standard for Bayesian model comparisons and hypothesis testing (Ly et al., 2015). In this approach, the observed data's probability ratio is calculated based on two competing hypotheses or models (Wei et al., 2022). Whereas the frequentist approach only indicates the lack of evidence against the null hypothesis rather than the evidence for the null hypothesis (Williams et al., 2017), the Bayes factor gives a continuous measure of evidence for either the null hypothesis or the alternative hypothesis (Dienes & Mclatchie, 2018). Thus, this type of analysis is an informative approach for conveying statistical findings in a broader range of conditions than the widely used p-value (Williams et al., 2017). In practice, a BF_{10} of 1 represents an equal prediction by both models, whereas a BF_{10} of <1 and >1 favors the null hypothesis and the alternative hypothesis, respectively (Dienes & Mclatchie, 2018; Wei et al., 2022). To put the Bayes factor into perspective, a BF_{10} of >3 often equals the amount of evidence obtained by p=<0.05 (Dienes & Mclatchie, 2018). In addition to the advantages mentioned above, neither the null hypothesis nor the alternative hypothesis must be “true” for the Bayes factor to be meaningful (Schönbrodt & Wagenmakers, 2018). Moreover, the fact that the Bayes factor gives a continuous measure of evidence for both models prohibits an all-or-nothing outcome from being forced, contrary to the p-value (Schönbrodt & Wagenmakers, 2018). Lastly, whereas the p-value is sensitive to sample sizes and statistical power, the Bayesian approach is regarded as a suitable option concerning small sample sizes (Schoot & Depaoili, 2014; Assaf & Tsionas, 2018), thus reducing the probability of making type II errors (Assaf & Tsionas, 2018). The low sample size and the lack of statistical power in this research study can lead to reliability issues (Button et al., 2013). Low powered research increases the risk of producing false negatives, reduces the probability that the observed effect reflects an actual effect, and increases the likelihood of the effect being exaggerated (Button et al., 2013). Therefore, our primary motivation for choosing the Bayesian approach was to reduce the reliability issues concerning the small sample size and the lack of statistical power in order to provide as accurate results as possible despite the aforementioned methodological challenges.

4.3 Participants

The subjects consisted of 11 professional soccer players (defenders n=5, midfielders n=4 and attackers n=2) playing at the second-highest level in Norway, possibly limiting the potential of generalizing the findings beyond this population. Moreover, there may be tactical and individual differences between the teams at this playing level, limiting the possibility of generalizing the findings to other teams at the same playing level. Further limitations include the relatively low sample size, which ruled out the possibility of categorizing the players into playing positions, which could have been beneficial due to the positional differences in match physical performance presented in chapters 2.2-2.2.2. One method to increase the sample size would have been by utilizing a different research design and a longer data collection period. Additionally, the sample size could have been expanded by reducing the playing time threshold, as this threshold excluded ten players from the analysis. However, the inclusion criteria were determined to increase the homogeneity and reduce the risk of confounding factors skewing the results, which ultimately may have increased the validity of the research.

4.4 Testing

The norm in soccer sprint testing is distances in the range of 5-40 m (Svensson & Drust, 2005; Turner et al., 2011; Haugen et al., 2014a), which covers the mean sprinting distances reported in Di Salvo et al. (2009), Bradley et al. (2010) and Ingebrigtsen et al. (2015). Additionally, 5- and 10-m sprints from a standstill start are valid and reliable methods to assess soccer-specific acceleration ability (Walker & Turner, 2009). Based on these recommendations, it is plausible that a 30-m sprint with split times has good ecological validity for soccer match play. As previously mentioned, starting methods, type of timing equipment, placement of timing equipment, the distance of flying start, surface, and environmental factors can significantly affect sprint performance results. Concerning these challenges, various measures were implemented to increase the accuracy and reliability of the lab-sprint test.

Firstly, the sprint test was standardized and identical for every subject. Further measures to optimize testing accuracy included starting the sprint with a staggered stance, which is a stance that is likely to be similar to how a sprint is initiated during match play. In terms of timing equipment, photocells have been shown to provide acceptable accuracy, although not regarded as the gold standard for sprint testing (Haugen & Buchheit, 2016). In this research study, dual-beamed photocells were utilized, which has obtained good accuracy and reliability (0.02 seconds SEM and CV~1%) for short sprinting and provides greater accuracy (Haugen & Buchheit, 2016) and fewer false starts than single-beamed photocells (Earp & Newton, 2012). Concerning photocell placement, the photocells were placed at 120 cm height, which is in line with the recommendations of Haugen & Buchheit (2016).

Moreover, as the distance of flying start has been shown to significantly influence sprint results (Haugen et al., 2015), the subjects initiated the sprint 0 cm from the starting line. Additionally, our lab-sprint testing protocol is in line with the suggestions of Walker & Turner, 2009) of performing a minimum of three trials and using the fastest time in the data analysis. Lastly, the sprint testing was located indoors to eliminate the influence of various environmental factors. However, indoor testing on a synthetic sports floor may have altered the ecological validity, as the players generally sprint outdoors on artificial turf or grass wearing soccer boots during match play. Further limitations include that the players only assessed sprint performance one day, which may have led to some players under/overperforming on the test day. Additionally, the ecological validity of the sprint test may have been increased by conducting the sprints from a flying start, as sprints during match play rarely are initiated from a standstill position (Svensson & Drust, 2005; Di Salvo et al., 2010).

4.5 Player monitoring

One strength of this research study is the validity and reliability of the monitoring technology (presented in chapters 2.1.1-2.1.2) that was used to assess the players' match activities. Although the validity and reliability of 10Hz GNSS devices are high, monitoring technology is associated with some level of error (Abbott, 2018a, p. 169). 10Hz devices possess SEM 5.1 - 10.9% and CV 0.7-5.0% during 15- and 30-m sprinting (Castellano et al., 2011; Scott et al., 2016), which is acceptable reliability for quantifying sprinting movements. However, the possibility of errors influencing the results cannot be ruled out (Abbott, 2018a, p. 169).

Furthermore, the players were familiar with using the GNSS devices as they had used them to monitor training and match load for an extended period prior to this research study. Thus, the risk of the players changing their on-field behavior due to being monitored may have been eliminated. Lastly, the players were always instructed to use the same units, as Nicolella et al. (2018) suggested, to ensure interunit reliability. It was decided that the players had to reach the playing time threshold in a minimum of four games, as great match-to-match variations in high-speed running have been reported during professional soccer match play (Carling et al., 2016; Oliva-Lozano et al., 2021).

A limitation regarding player monitoring may be that the number of matches where the players reached the playing time threshold ranged from 4 to 7, which resulted in certain players providing as many as three more observations than the players on the lower end of the playing time threshold, which ultimately may have influenced the results.

In terms of confounding factors, multiple contextual, situational, and tactical factors (described in chapter 2.2.1) may have influenced match physical performance during the data collection period. Further limitations may include the relatively short monitoring period containing relatively few matches. Moreover, the resistance training intervention may have altered match physical performance, despite low resistance training frequency and volume. Lastly, the locomotive activity thresholds were pre-fixed by the manufacturer, which may be regarded as a limitation due to individually dependent movement speed (Abt & Lovell, 2009; Gabbett, 2015; Abbott et al., 2018b). Thus, as suggested in Gabbett (2015), using individual thresholds based on lab-sprint performance may have been a more suitable option to accurately quantify physical performance during match play.

4.6 Summary of strengths and limitations

The main strength of this research study is that the research design demanded minimal effort from the subjects beyond what they already did daily. Furthermore, the researchers only interacted with the subjects during the testing, which led to minimal interference with their training and match preparations during the data collection period. The second strength concerns the reliability and validity of the equipment and protocols during lab testing and player monitoring. In terms of the limitations of this research, the main weakness is the use of an observational research design, which limits the possibility of drawing causal relationships. Additionally, the small sample size is also a limitation, albeit measures were taken during the statistical analysis to reduce the significance of the low number of subjects.

5.0 References

Abbott, W. (2018a). *Monitoring and prescription of GPS training load in elite academy soccer athletes* [Doctoral thesis, University of Brighton]. Research.Brighton.ac.uk. https://research.brighton.ac.uk/en/studentTheses/monitoring-and-prescription-of-gps-training-load-in-elite-academy

Abbott, W., Brickley, G., & Smeeton, N. (2018b). Physical demands of playing position within English Premier League academy soccer. *Journal of Human Sport and Exercise*, *13*(2), 285-295. https://doi.org/10.14198/jhse.2018.132.04

Abt, G., & Lovell, R. (2009). The use of individualized speed and intensity thresholds for determining the distance run at high-intensity in professional soccer. *Journal of Sports Sciences*, *27*(9), 893-898. https://doi.org/10.1080/02640410902998239

Ade, J., Fitzpatrick, J., & Bradley, P. S. (2016). High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions. Information for position-specific training drills. *Journal of Sports Sciences*, *34*(24), 2205-2214. https://doi.org/10.1080/02640414.2016.1217343

Ahmad, N., Raja Ghazilla, R. A., Khairi, N., & Kasi, V. (2013). Reviews on Various Inertial Measurement Unit (IMU) Sensor Applications. *International Journal of Signal Processing Systems*, *1*(2), 256-262. https://doi.org/10.12720/ijsps.1.2.256-262

Akenhead, R., French, D., Thompson, K. G., & Hayes, P. R. (2014). The acceleration dependent validity and reliability of 10Hz GPS. *Journal of Science and Medicine in Sport*, *17*(5), 562-566. https://doi.org/10.1016/j.jsams.2013.08.005

Andrzejewski, M., Chmura, J., Pluta, B., Strzelczyk, R., & Kasprzak, A. (2013). Analysis of Sprinting Activities of Professional Soccer Players. *The Journal of Strength & Conditioning Research*, *27*(8), 2134-2140. https://doi.org/10.1519/JSC.0b013e318279423e

Aquino, R., Carling, C., Palucci Vieira, L., Martins, G., Jabor, G., Machado, J. C., Santiago, P., Garganta, J., & Puggina, E. (2020). Influence of Situational Variables, Team Formation, and Playing Position on Match Running Performance and Social Network Analysis in Brazilian Professional Soccer Players. *The Journal of Strength and Conditioning Research*, *34*(3), 808-817. https://doi.org/10.1519/JSC.0000000000002725

Barnes, C., Archer, D. T., Hogg, B., Bush, M., & Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine, 35*(13), 1095-1100. https://doi.org/10.1055/s-0034-1375695

Barrett, S., Midgley, A., Towlson, C., Garrett, A., Portas, M., & Lovell, R. (2015). Within-Match PlayerLoadTM Patterns During a Simulated Soccer Match (SAFT90): Potential Implications for Unit Positioning and Fatigue Management. *International Journal of Sports Physiology and Performance, 11*(1), 135-140. https://doi.org/10.1123/ijspp.2014-0582

Baptista, I., Johansen, D., Seabra, A., & Pettersen, S, A. (2018) Position specific player load during match-play in a professional football club. *PLOS ONE, 13(5)*, e0198115. https://doi.org/10.1371/journal.pone.0198115

Baumgart, C., Freiwald, J., & Hoppe, M. W. (2018). Sprint Mechanical Properties of Female and Different Aged Male Top-Level German Soccer Players. *Sports (Basel), 6*(4), 161. https://doi.org/10.3390/sports6040161

Beato, M., Coratella, G., Stiff, A., & Iacono, A. D. (2018). The Validity and Between-Unit Variability of GNSS Units (STATSports Apex 10 and 18 Hz) for Measuring Distance and Peak Speed in Team Sports. *Frontiers in Physiology, 9*(1288). https://doi.org/10.3389/fphys.2018.01288

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical Demands of Different Positions in FA Premier League Soccer. *Journal of Sports Science & Medicine, 6*(1), 63-70.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring Athlete Training Loads: Consensus Statement. *International Journal of Sports Physiology and Performance, 12*(2), 161-170. https://doi.org/10.1123/ijspp.2017-0208

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *International Journal of Sports Physiology and Performance, 6*(3), 311-321. https://doi.org/10.1123/ijspp.6.3.311

Boyko, E. J. (2013). Observational research — opportunities and limitations. *Journal of Diabetes and its Complications, 27*(6), 642-648. https://doi.org/10.1016/j.jdiacomp.2013.07.007

Bradley, P. S., Di Mascio, M., Peart, D., Olsen, P., & Sheldon, B. (2010). High-Intensity Activity Profiles of Elite Soccer Players at Different Performance Levels. *The Journal of Strength & Conditioning Research, 24*(9), 2343-2351. https://doi.org/10.1519/JSC.0b013e3181aeb1b3

Brechue, W., Mayhew, J., & Piper, F. (2005). Equipment and Running Surface Alter Sprint Performance of College Football Players. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 19*(4), 821-825. https://doi.org/10.1519/R-16934.1

Bredt, S. d. G. T., Chagas, M. H., Peixoto, G. H., Menzel, H. J., & de Andrade, A. G. P. (2020). Understanding Player Load: Meanings and Limitations. *Journal of Human Kinetics, 71*, 5-9. https://doi.org/10.2478/hukin-2019-0072

Button, K. S., Ioannidis, J. P. A., Mokrysz, C., Nosek, B. A., Flint, J., Robinson, E. S. J., & Munafò, M. R. (2013). Power failure: why small sample size undermines the reliability of neuroscience. *Nature Reviews Neuroscience, 14*(5), 365-376. https://doi.org/10.1038/nrn3475

Caldbeck, P. (2020). *CONTEXTUAL SPRINTING IN PREMIER LEAGUE FOOTBALL*. [Doctoral thesis, Liverpool John Moores University]. LJMU Research Online. http://researchonline.ljmu.ac.uk/id/eprint/13617/

Carling, C., Bloomfield, J., Nelson, L., & Reilly, T. (2008). The Role of Motion Analysis in Elite Soccer. *Sports Medicine, 38*(10), 839-862. https://doi.org/10.2165/00007256-200838100-00004

Carling, C., Bradley, P., McCall, A., & Dupont, G. (2016). Match-to-match variability in high-speed running activity in a professional soccer team. *Journal of Sports Sciences, 34*(24), 2215-2223. https://doi.org/10.1080/02640414.2016.1176228

Casajus, J. (2001). Seasonal variation in fitness variables in professional soccer player. *The Journal of Sports Medicine and Physical Fitness, 41*(4), 463-469.

Castellano, J., Alvarez-Pastor, D., & Bradley, P. S. (2014). Evaluation of Research Using Computerised Tracking Systems (Amisco® and Prozone®) to Analyse Physical Performance in Elite Soccer: A Systematic Review. *Sports Medicine, 44*(5), 701-712. https://doi.org/10.1007/s40279-014-0144-3

Castellano, J., Casamichana, D., Calleja Gonzalez, J., Román, J., & Ostojic, S. (2011). Reliability and Accuracy of 10 Hz GPS Devices for Short-Distance Exercise. *Journal of Sports Science & Medicine, 10*(1), 233-234.

Castillo, D., Weston, M., McLaren, S. J., Cámara, J., & Yanci, J. (2017). Relationships Between Internal and External Match-Load Indicators in Soccer Match Officials. *International Journal of Sports Physiology and Performance*, *12*(7), 922-927. https://doi.org/10.1123/ijspp.2016-0392

Chambers, R., Gabbett, T. J., Cole, M. H., & Beard, A. (2015). The Use of Wearable Microsensors to Quantify Sport-Specific Movements. *Sports Medicine*, *45*(7), 1065-1081. https://doi.org/10.1007/s40279-015-0332-9

Chaouachi, A., Brughelli, M., Chamari, K., Levin, G. T., Abdelkrim, N. B., Laurencelle, L., & Castagna, C. (2009). Lower Limb Maximal Dynamic Strength and Agility Determinants in Elite Basketball Players. *The Journal of Strength & Conditioning Research*, *23*(5), 1570-1577. https://doi.org/10.1519/JSC.0b013e3181a4e7f0

Chelly, M. S., Fathloun, M., Cherif, N., Amar, M. B., Tabka, Z., & Van Praagh, E. (2009). Effects of a Back Squat Training Program on Leg Power, Jump, and Sprint Performances in Junior Soccer Players. *The Journal of Strength & Conditioning Research*, *23*(8), 2241-2249. https://doi.org/10.1519/JSC.0b013e3181b86c40

Chmura, P., Andrzejewski, M., Konefał, M., Mroczek, D., Rokita, A., & Chmura, J. (2017). Analysis of Motor Activities of Professional Soccer Players during the 2014 World Cup in Brazil. *Journal of Human Kinetics*, *56*(1), 187-195. https://doi.org/10.1515/hukin-2017-0036

Chumanov, E. S., Heiderscheit, B. C., & Thelen, D. G. (2011). Hamstring musculotendon dynamics during stance and swing phases of high-speed running. *Medicine and Science in Sports and Exercise*, *43*(3), 525-532. https://doi.org/10.1249/MSS.0b013e3181f23fe8

Churchill, S. M., Salo, A. I., & Trewartha, G. (2015). The effect of the bend on technique and performance during maximal effort sprinting. *Sports Biomechanics*, *14*(1), 106-121. https://doi.org/10.1080/14763141.2015.1024717

Churchill, S. M., Trewartha, G., Bezodis, I. N., & Salo, A. I. (2016). Force production during maximal effort bend sprinting: Theory vs reality. *Scandinavian Journal of Medicine & Science in Sports*, *26*(10), 1171-1179. https://doi.org/10.1111/sms.12559

Cometti, G., Maffiuletti, N., Pousson, M., Chatard, J.-C., & Maffulli, N. (2001). Isokinetic Strength and Anaerobic Power of Elite, Subelite and Amateur French Soccer Players. *International Journal of Sports Medicine*, *22*(1), 45-51. https://doi.org/10.1055/s-2001-11331

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011a). Developing maximal neuromuscular power: Part 1--biological basis of maximal power production. *Sports Medicine (Auckland, N.Z.), 41*(1), 17-38. https://doi.org/10.2165/11537690-000000000-00000

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011b). Developing maximal neuromuscular power: part 2 - training considerations for improving maximal power production. *Sports Medicine (Auckland, N.Z.), 41*(2), 125-146. https://doi.org/10.2165/11538500-000000000-00000

Cotte, T., & Chatard, J.-C. (2011). Isokinetic strength and sprint times in English Premier League football players. *Biology of Sport, 28*(2), 89-94.

Cronin, J. B., & Templeton, R. L. (2008). Timing Light Height Affects Sprint Times. *The Journal of Strength & Conditioning Research, 22*(1), 318-320. https://doi.org/10.1519/JSC.0b013e31815fa3d3

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Medicine, 43*(10), 1025-1042. https://doi.org/10.1007/s40279-013-0069-2

Dalen, T., Jørgen, I., Gertjan, E., Geir Havard, H., & Ulrik, W. (2016). Player Load, Acceleration, and Deceleration During Forty-Five Competitive Matches of Elite Soccer. *The Journal of Strength & Conditioning Research, 30*(2), 251-259. https://doi.org/10.1519/JSC.0000000000001063

Delecluse, C. (1997). Influence of Strength Training on Sprint Running Performance. *Sports Medicine, 24*(3), 147-156. https://doi.org/10.2165/00007256-199724030-00001

Di Salvo, V., Baron, R., González-Haro, C., Gormasz, C., Pigozzi, F., & Bachl, N. (2010). Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. *Journal of Sports Sciences, 28*(14), 1489-1494. https://doi.org/10.1080/02640414.2010.521166

Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F. J., Bachl, N., & Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine, 28*(3), 222-227. https://doi.org/10.1055/s-2006-924294

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of High Intensity Activity in Premier League Soccer. *International Journal of Sports Medicine, 30*(3), 205-212. https://doi.org/10.1055/s-0028-1105950

Dienes, Z., & McLatchie, N. (2018). Four reasons to prefer Bayesian analyses over significance testing. *Psychonomic Bulletin & Review, 25*(1), 207-218. https://doi.org/10.3758/s13423-017-1266-z

Dolci, F., Hart, N. H., Kilding, A., Chivers, P., Piggott, B., & Spiteri, T. (2018). Movement Economy in Soccer: Current Data and Limitations. *Sports (Basel), 6*(4), 124. https://doi.org/10.3390/sports6040124

Drozd, M., Krzysztofik, M., Nawrocka, M., Krawczyk, M., Kotuła, K., Langer, A., & Maszczyk, A. (2017). Analysis of the 30-m running speed test results in soccer players in third soccer leagues. *Turkish Journal of Kinesiology, 3*(1), 1-5.

Dunbar, J., & Power, K. (1995). Fitness profiles of English Professional & semi-professional soccer players using a battery of tests. In T. Reilly, Bangsbo, M., & Hughes, M (Ed.), *Science and Football III* (1 ed., pp. 27-31). E & F N Spon.

Dunbar, J., & Treasure, D. (2005). An analysis of fitness profiles as a function of playing position and playing level in three English Premier League soccer clubs. In T. Reilly, Cabri, J., & Araujo, D. (Ed.), *Science and Football V* (1 ed., pp. 160-164). Routledge.

Dwivedi, A. K., Mallawaarachchi, I., & Alvarado, L. A. (2017). Analysis of small sample size studies using nonparametric bootstrap test with pooled resampling method. *Statistics in Medicine, 36*(14), 2187-2205. https://doi.org/10.1002/sim.7263

Earp, J. E., & Newton, R. U. (2012). Advances in Electronic Timing Systems: Considerations for Selecting an Appropriate Timing System. *The Journal of Strength & Conditioning Research, 26*(5), 1245-1248. https://doi.org/10.1519/JSC.0b013e3182474436

Edholm, P., Krustrup, P., & Randers, M. B. (2014). Half-time re-warm up increases performance capacity in male elite soccer players. *Scandinavian Journal of Medicine & Science in Sports, 25*(1), 40-49. https://doi.org/10.1111/sms.12236

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences, 30*(7), 625-631. https://doi.org/10.1080/02640414.2012.665940

Fitzpatrick, J., Linsley, A., & Musham, C. (2019). Running the curve: a preliminary investigation into curved sprinting during football match-play. *Sport Performance & Science Reports, 1*.

Gabbett, T. J. (2015). Use of Relative Speed Zones Increases the High-Speed Running Performed in Team Sport Match Play. *The Journal of Strength & Conditioning Research, 29*(12), 3353-3359. https://doi.org/10.1519/JSC.0000000000001016

George Assaf, A., & Tsionas, M. (2018). Bayes factors vs. P-values. *Tourism Management, 67*, 17-31. https://doi.org/10.1016/j.tourman.2017.11.011

Gil, S., Barroso, R., Carmo, E., Loturco, I., Kobal, R., Tricoli, V., Ugrinowitsch, C., & Roschel, H. (2018). Effects of resisted sprint training on sprinting ability and change of direction speed in professional soccer players. *Journal of Sports Sciences, 36*(17), 1923-1929. https://doi.org/10.1080/02640414.2018.1426346

Gómez-Carmona, C. D., Bastida-Castillo, A., Ibáñez, S. J., & Pino-Ortega, J. (2020). Accelerometry as a method for external workload monitoring in invasion team sports. A systematic review. *PLOS ONE, 15*(8), e0236643. https://doi.org/10.1371/journal.pone.0236643

Gorostiaga, E. M., Llodio, I., Ibáñez, J., Granados, C., Navarro, I., Ruesta, M., Bonnabau, H., & Izquierdo, M. (2009). Differences in physical fitness among indoor and outdoor elite male soccer players. *European Journal of Applied Physiology, 106*(4), 483-491. https://doi.org/10.1007/s00421-009-1040-7

Granero-Gil, P., Gómez-Carmona, C. D., Bastida-Castillo, A., Rojas-Valverde, D., de la Cruz, E., & Pino-Ortega, J. (2020). Influence of playing position and laterality in centripetal force and changes of direction in elite soccer players. *PLOS ONE, 15*(4), e0232123. https://doi.org/10.1371/journal.pone.0232123

Haff, G. G., & Nimphius, S. (2012). Training Principles for Power. *Strength & Conditioning Journal, 34*(6), 2-12. https://doi.org/10.1519/SSC.0b013e31826db467

Hammami, M., Negra, Y., Billaut, F., Hermassi, S., Shephard, R. J., & Chelly, M. S. (2018). Effects of Lower-Limb Strength Training on Agility, Repeated Sprinting With Changes of Direction, Leg Peak Power, and Neuromuscular Adaptations of Soccer Players. *Journal of Strength and Conditioning Research, 32*(1), 37-47. https://doi.org/10.1519/jsc.0000000000001813

Haugen, T., & Buchheit, M. (2016). Sprint Running Performance Monitoring: Methodological and Practical Considerations. *Sports Medicine, 46*(5), 641-656. https://doi.org/10.1007/s40279-015-0446-0

Haugen, T., Tønnessen, E., & Seiler, S. (2013). Anaerobic Performance Testing of Professional Soccer Players 1995–2010. *International Journal of Sports Physiology and Performance, 8*(2), 148-156. https://doi.org/10.1123/ijspp.8.2.148

Haugen, T., Tønnessen, E., & Seiler, S. (2015). Correction Factors for Photocell Sprint Timing With Flying Start. *International Journal of Sports Physiology and Performance*, *10*(8), 1055-1057. https://doi.org/10.1123/ijspp.2014-0415

Haugen, T. A., Tønnessen, E., Hisdal, J., & Seiler, S. (2014a). The Role and Development of Sprinting Speed in Soccer. *International Journal of Sports Physiology and Performance*, *9*(3), 432-441. https://doi.org/10.1123/ijspp.2013-0121

Haugen, T. A., Tønnessen, E., & Seiler, S. K. (2012). The Difference Is in the Start: Impact of Timing and Start Procedure on Sprint Running Performance. *The Journal of Strength & Conditioning Research*, *26*(2), 479-479. https://doi.org/10.1519/JSC.0b013e318226030b

Haugen, T. A., Tønnessen, E., Svendsen, I. S., & Seiler, S. (2014b). Sprint Time Differences Between Single- and Dual-Beam Timing Systems. *The Journal of Strength & Conditioning Research*, *28*(8), 2376-2379. https://doi.org/10.1519/JSC.0000000000000415

Helgerud, J., Rodas, G., Kemi, O., & Hoff, J. (2011). Strength and Endurance in Elite Football Players. *International Journal of Sports Medicine*, *32*(9), 677-682. https://doi.org/10.1055/s-0031-1275742

Hennessy, L., & Jeffreys, I. (2018). The Current Use of GPS, Its Potential, and Limitations in Soccer. *Strength & Conditioning Journal*, *40*(3), 83-94. https://doi.org/10.1519/SSC.0000000000000386

Hess, A. S., & Abd-Elsayed, A. (2019). Observational Studies: Uses and Limitations. In A. Abd-Elsayed (Ed.), *Pain: A Review Guide* (pp. 123-125). Springer International Publishing. https://doi.org/10.1007/978-3-319-99124-5_31

Hewit, J., Cronin, J., Button, C., & Hume, P. (2011) Understanding Deceleration in Sport. *Strength and Conditioning Journal*, *33(1)*, 47-52.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009) Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise 41(1)*, 3-12. https://doi.org/10.1249/MSS.0b013e31818cb278

Howard, R. M., Conway, R., & Harrison, A. J. (2018). Muscle activity in sprinting: a review. *Sports Biomechanics*, *17*(1), 1-17. https://doi.org/10.1080/14763141.2016.1252790

Ingebrigtsen, J., Dalen, T., Hjelde, G. H., Drust, B., & Wisløff, U. (2015). Acceleration and sprint profiles of a professional elite football team in match play. *European Journal of Sport Science, 15*(2), 101-110. https://doi.org/10.1080/17461391.2014.933879

Jackson, B., Polglaze, T., Dawson, B., King, T., & Peeling, P. (2018). Comparing Global Positioning System (GPS) and Global Navigation Satellite System (GNSS) Measures of Team Sport Movements. *International Journal of Sports Physiology and Performance, 13*(8), 1005–1010. https://doi.org/10.1123/ijspp.2017-0529

Jennings, D., Cormack, S., Coutts, A. J., Boyd, L., & Aughey, R. J. (2010). The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *International Journal of Sports Physiology and Performance, 5*(3), 328-341. https://doi.org/10.1123/ijspp.5.3.328

Jullien, H., Bisch, C., Largouët, N., Manouvrier, C., Carling, C. J., & Amiard, V. (2008). Does A Short Period of Lower Limb Strength Training Improve Performance in Field-Based Tests of Running and Agility in Young Professional Soccer Players? *The Journal of Strength & Conditioning Research, 22*(2), 404-411. https://doi.org/10.1519/JSC.0b013e31816601e5

Kapri, E., Mehta, M., & S, K. (2021). Biomechanics of running: An overview on gait cycle. *International Journal of Physical Education, Fitness and Sports, 10*(5), 1-9. https://doi.org/10.34256/ijpefs2131

Kovacs, M., Roetert, E. P., & Ellenbecker, T. (2008). Efficient Deceleration: The Forgotten Factor in Tennis-Specific Training. *Strength & Conditioning Journal, 30*(6), 58-69. https://doi.org/10.1519/SSC.0b013e31818e5fbc

Krasnoff, J. B., Kohn, M. A., Choy, F. K., Doyle, J., Johansen, K., & Painter, P. L. (2008). Interunit and intraunit reliability of the RT3 triaxial accelerometer. *Journal of Physical Activity & Health, 5*(4), 527-538. https://doi.org/10.1123/jpah.5.4.527

Krommes, K., Petersen, J., Nielsen, M. B., Aagaard, P., Hölmich, P., & Thorborg, K. (2017). Sprint and jump performance in elite male soccer players following a 10-week Nordic Hamstring exercise Protocol: a randomised pilot study. *BMC Research Notes, 10*(1), 669. https://doi.org/10.1186/s13104-017-2986-x

Lago-Peñas, C. (2012). The role of situational variables in analysing physical performance in soccer. *Journal of Human Kinetics, 35*, 89-95. https://doi.org/10.2478/v10078-012-0082-9

Lago-Peñas, C., Rey, E., Lago-Ballesteros, J., Casais, L., & Domínguez, E. (2009). Analysis of work-rate in soccer according to playing positions. *International Journal of Performance Analysis in Sport*, *9*(2), 218-227. https://doi.org/10.1080/24748668.2009.11868478

Li, X., Ge, M., Dai, X., Ren, X., Fritsche, M., Wickert, J., & Schuh, H. (2015). Accuracy and reliability of multi-GNSS real-time precise positioning: GPS, GLONASS, BeiDou, and Galileo. *Journal of Geodesy, 89*(6), 607-635. https://doi.org/10.1007/s00190-015-0802-8

Little, T., & Williams, A. G. (2005). Specificity of acceleration, maximum speed, and agility in professional soccer players. *Journal of Strength and Conditioning Research, 19*(1), 76-78. https://doi.org/10.1519/14253.1

Loturco, I., Kobal, R., Kitamura, K., Fernandes, V., Moura, N., Siqueira, F., Cal Abad, C. C., & Pereira, L. A. (2019). Predictive Factors of Elite Sprint Performance: Influences of Muscle Mechanical Properties and Functional Parameters. *Journal of Strength and Conditioning Research, 33*(4), 974-986. https://doi.org/10.1519/jsc.0000000000002196

Loturco, I., Pereira, L. A., Fílter, A., Olivares-Jabalera, J., Reis, V. P., Fernandes, V., Freitas, T. T., & Requena, B. (2020). Curve sprinting in soccer: relationship with linear sprints and vertical jump performance. *Biology of Sport, 37*(3), 277-283. https://doi.org/10.5114/biolsport.2020.96271

Luteberget, L. S., Holme, B. R., & Spencer, M. (2018a). Reliability of Wearable Inertial Measurement Units to Measure Physical Activity in Team Handball. *International Journal of Sports Physiology and Performance, 13*(4), 467-473. https://doi.org/10.1123/ijspp.2017-0036

Luteberget, L. S., Spencer, M., & Gilgien, M. (2018b). Validity of the Catapult ClearSky T6 Local Positioning System for Team Sports Specific Drills, in Indoor Conditions. *Frontiers in Physiology, 9*(115). https://doi.org/10.3389/fphys.2018.00115

Ly, A., Verhagen, A. J., & Wagenmakers, E.-J. (2015). Harold Jeffreys's default Bayes factor hypothesis tests: Explanation, extension, and application in psychology. *Journal of Mathematical Psychology, 72*, 19-32. https://doi.org/10.1016/j.jmp.2015.06.004

McBride, J. M., Blow, D., Kirby, T. J., Haines, T. L., Dayne, A. M., & Triplett, N. T. (2009). Relationship Between Maximal Squat Strength and Five, Ten, and Forty Yard Sprint Times. *The Journal of Strength & Conditioning Research, 23*(6), 1633-1636. https://doi.org/10.1519/JSC.0b013e3181b2b8aa

McMorrow, B. J., Ditroilo, M., & Egan, B. (2019). Effect of Heavy Resisted Sled Sprint Training During the Competitive Season on Sprint and Change-of-Direction Performance in Professional Soccer Players. *International Journal of Sports Physiology and Performance, 14*(8), 1066-1073. https://doi.org/10.1123/ijspp.2018-0592

Mero, A., Komi, P, V., & Gregor, R, J. (1992) Biomechanics of sprint running. A review. *Sports Medicine (Auckland, N.Z.), 13 (6)*, 376-392. https://doi.org/10.2165/00007256-199213060-00002

Mitrotasios, M., Ispirlidis, I., Mantzouranis, N., Vassiliades, E., & Armatas, V. (2021). Season physical performance of professional soccer players. Match-play evaluation of a Greek Super League team. *Journal of Physical Education and Sport, 21*(2), 743-747. https://doi.org/10.7752/jpes.2021.02092

Modric, T., Versic, S., & Sekulic, D. (2020). Position Specific Running Performances in Professional Football (Soccer): Influence of Different Tactical Formations. *Sports (Basel), 8*(12), 161. https://doi.org/10.3390/sports8120161

Modric, T., Versic, S., Sekulic, D., & Liposek, S. (2019). Analysis of the Association between Running Performance and Game Performance Indicators in Professional Soccer Players. *International Journal of Environmental Research and Public Health, 16*(20), 4032. https://doi.org/10.3390/ijerph16204032

Montgomery, P. G., Pyne, D. B., & Minahan, C. L. (2010). The physical and physiological demands of basketball training and competition. *International Journal of Sports Physiology and Performance, 5*(1), 75-86. https://doi.org/10.1123/ijspp.5.1.75

Morgans, R., Orme, P., Anderson, L., & Drust, B. (2014). Principles and practices of training for soccer. *Journal of Sport and Health Science, 3*(4), 251-257. https://doi.org/10.1016/j.jshs.2014.07.002

Nicolella, D. P., Torres-Ronda, L., Saylor, K. J., & Schelling, X. (2018). Validity and reliability of an accelerometer-based player tracking device. *PLOS ONE, 13*(2), e0191823. https://doi.org/10.1371/journal.pone.0191823

Novacheck, T. F. (1998). The biomechanics of running. *Gait & Posture, 7*(1), 77-95. https://doi.org/10.1016/S0966-6362(97)00038-6

Oliva-Lozano, J. M., Muyor, J. M., Fortes, V., & McLaren, S. J. (2021). Decomposing the variability of match physical performance in professional soccer: Implications for monitoring individuals. *European Journal of Sport Science, 21*(11), 1588-1596. https://doi.org/10.1080/17461391.2020.1842513

Osgnach, C., Poser, S., Bernardini, R., Rinaldo, R., & Di Prampero, P. E. (2010). Energy Cost and Metabolic Power in Elite Soccer: A New Match Analysis Approach. *Medicine & Science in Sports & Exercise*, *42*(1), 170-178. https://doi.org/10.1249/MSS.0b013e3181ae5cfd

Paul, D. J., Bradley, P. S., & Nassis, G. P. (2015). Factors affecting match running performance of elite soccer players: shedding some light on the complexity. *International Journal of Sports Physiology and Performance*, *10*(4), 516-519. https://doi.org/10.1123/ijspp.2015-0029

Polit, D. F., & Beck, C. H. (2018). *Essenstials of Nursing Research: Appraising Evidence for Nursing Practice* (9 ed.). Wolters Kluwer.

Pons, E., García-Calvo, T., Resta, R., Blanco, H., López del Campo, R., Díaz García, J., & Pulido, J. J. (2019). A comparison of a GPS device and a multi-camera video technology during official soccer matches: Agreement between systems. *PLOS ONE, 14*(8), e0220729. https://doi.org/10.1371/journal.pone.0220729

Quintana, D. S., & Williams, D. R. (2018). Bayesian alternatives for common null-hypothesis significance tests in psychiatry: a non-technical guide using JASP. *BMC Psychiatry, 18*(1), 178. https://doi.org/10.1186/s12888-018-1761-4

Requena, B., García, I., Suarez-Arrones, L., Sáez de Villarreal, E., Naranjo Orellana, J., & Santalla, A. (2016). Off-Season Effects on Functional Performance, Body Composition, and Blood Parameters in Top-Level Professional Soccer Players. *Journal of Strength and Conditioning Research, 31*(4), 939-946. https://doi.org/10.1519/JSC.0000000000001568

Reynolds, J., Connor, M., Jamil, M., & Beato, M. (2021). Quantifying and Comparing the Match Demands of U18, U23, and 1ST Team English Professional Soccer Players. *Frontiers in Physiology*, *12*, 706451. https://doi.org/10.3389/fphys.2021.706451

Ross, A., Leveritt, M., & Riek, S. (2001). Neural influences on sprint running training adaptations and acute responses. *Sports Medicine (Auckland, N.Z.), 31*(6), 409-425. https://doi.org/10.2165/00007256-200131060-00002

Rumpf, M., Lockie, R., Cronin, J., & Jalilvand, F. (2016). BRIEF REVIEW EFFECT OF DIFFERENT SPRINT TRAINING METHODS ON SPRINT PERFORMANCE OVER VARIOUS DISTANCES: A BRIEF REVIEW. *The Journal of Strength and Conditioning Research, 30*(6), 1767-1785. https://doi.org/10.1519/JSC.0000000000001245

Rønnestad, B., Kvamme, N., Sunde, A., & Raastad, T. (2008). Short-Term Effects of Strength and Plyometric Training on Sprint and Jump Performance in Professional Soccer Players. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 22*(3), 773-380. https://doi.org/10.1519/JSC.0b013e31816a5e86

Raastad, T., Paulsen, G., Refsnes, P, E., Rønnestad, B, R., & Wisnes, A, R. . (2010). *Styrketrening- i teori og praksis*. Gyldendal undervisning.

Schmalz, X., Biurrun Manresa, J., & Zhang, L. (2021). What is a Bayes factor? *Psychological Methods*. https://doi.org/10.1037/met0000421

Schoot, R., & Depaoli, S. (2014). Bayesian analyses: Where to start and what to report. *The European Health Psychologist, 16*(2), 75-84.

Schönbrodt, F. D., & Wagenmakers, E. J. (2018). Bayes factor design analysis: Planning for compelling evidence. *Psychonomic Bulletin & Review, 25*(1), 128-142. https://doi.org/10.3758/s13423-017-1230-y

Scott, M. T. U., Scott, T. J., & Kelly, V. G. (2016). The Validity and Reliability of Global Positioning Systems in Team Sport: A Brief Review. *The Journal of Strength & Conditioning Research, 30*(5), 1470-1490. https://doi.org/10.1519/JSC.0000000000001221

Sheppard, J., & Young, W. (2006). Agility Literature Review: Classifications, Training and Testing *Journal of Sports Sciences, 24*(9), 919-932. https://doi.org/10.1080/02640410500457109

Silva, J. R., Magalhães, J., Ascensão, A., Seabra, A. F., & Rebelo, A. N. (2013). Training Status and Match Activity of Professional Soccer Players Throughout a Season. *The Journal of Strength & Conditioning Research, 27*(1), 20-30. https://doi.org/10.1519/JSC.0b013e31824e1946

Siti Azilah, A., Foskett, A., & Ali, A. (2019) Special Populations: Issues and Considerations in Youth Soccer Match Analysis. *International Journal of Sports Science, 4(3),* 103-114.

Souza, P. (2021a). *Vector User Guide (PDF)*. Catapult Sports. Retrieved 17.02.2022 from https://support.catapultsports.com/hc/en-us/articles/360001040676-Vector-User-Guide-PDF-

Souza, P. (2021b). *Vector S7 & G7 Overview*. Catapult Sports. Retrieved 17.02.2022 from https://support.catapultsports.com/hc/en-us/articles/360000919456-Vector-S7-G7-Overview

Sporis, G., Jukic, I., Ostojic, S. M., & Milanovic, D. (2009). Fitness profiling in soccer: physical and physiologic characteristics of elite players. *Journal of Strength and Conditioning Research, 23*(7), 1947-1953. https://doi.org/10.1519/JSC.0b013e3181b3e141

Styles, W. J., Matthews, M. J., & Comfort, P. (2016). Effects of Strength Training on Squat and Sprint Performance in Soccer Players. *Journal of Strength and Conditioning Research, 30*(6), 1534-1539. https://doi.org/10.1519/jsc.0000000000001243

Svensson, M., & Drust, B. (2005). Testing soccer players. *Journal of Sports Sciences, 23*(6), 601-618. https://doi.org/10.1080/02640410400021294

Sweeting, A. J., Cormack, S. J., Morgan, S., & Aughey, R. J. (2017). When Is a Sprint a Sprint? A Review of the Analysis of Team-Sport Athlete Activity Profile. *Frontiers in Physiology, 8*(432). https://doi.org/10.3389/fphys.2017.00432

TaŞkin, H. (2008). Evaluating Sprinting Ability, Density of Acceleration, and Speed Dribbling Ability of Professional Soccer Players With Respect to Their Positions. *The Journal of Strength & Conditioning Research, 22*(5), 1481-1486. https://doi.org/10.1519/JSC.0b013e318181fd90

Taylor, J. B., Wright, A. A., Dischiavi, S. L., Townsend, M. A., & Marmon, A. R. (2017). Activity Demands During Multi-Directional Team Sports: A Systematic Review. *Sports Medicine, 47*(12), 2533-2551. https://doi.org/10.1007/s40279-017-0772-5

Taylor, M. J., & Beneke, R. (2012). Spring mass characteristics of the fastest men on Earth. *International Journal of Sports Medicine, 33*(8), 667-670. https://doi.org/10.1055/s-0032-1306283

Theodoropoulos, J. S., Bettle, J., & Kosy, J. D. (2020). The use of GPS and inertial devices for player monitoring in team sports: A review of current and future applications. *Orthopedic Reviews, 12*(1), 7863-7863. https://doi.org/10.4081/or.2020.7863

Torres-Ronda, L., Beanland, E., Whitehead, S., Sweeting, A., & Clubb, J. (2022). Tracking Systems in Team Sports: A Narrative Review of Applications of the Data and Sport Specific Analysis. *Sports Medicine - Open, 8*(1), 15. https://doi.org/10.1186/s40798-022-00408-z

Turner, A., Walker, S., Stembridge, M., Coneyworth, P., Reed, G., Birdsey, L., Barter, P., & Moody, J. (2011). A Testing Battery for the Assessment of Fitness in Soccer Players. *Strength & Conditioning Journal, 33*(5), 29-39. https://doi.org/10.1519/SSC.0b013e31822fc80a

Varley, M. C., & Aughey, R. J. (2013) Acceleration profiles in elite Australian soccer. *International Journal of Sports Medicine, 34(1)*, 34-39. https://doi.org/10.1055/s-0032-1316315

Varley, M. C., Fairweather, I. H., & Aughey, R. J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion *Journal of Sports Sciences, 30*(2), 121-127. https://doi.org/10.1080/02640414.2011.627941

Varley, M. C., Gabbett, T., & Aughey, R. J. (2014). Activity profiles of professional soccer, rugby league and Australian football match play. *Journal of Sports Sciences, 32*(20), 1858-1866. https://doi.org/10.1080/02640414.2013.823227

Vigh-Larsen, J. F., Dalgas, U., & Andersen, T.B. (2018) Position-Specific Acceleration and Deceleration Profiles in Elite Youth and Senior Soccer Players. *Journal of Strength and Conditioning Research, 32(4)*, 1114-1122. https://doi.org/10.1519/JSC.0000000000001918

Vigne, G., Gaudino, C., Rogowski, I., Alloatti, G., & Hautier, C. (2010). Activity profile in elite Italian soccer team. *International Journal of Sports Medicine, 31*(5), 304-310. https://doi.org/10.1055/s-0030-1248320

Vilamitjana, J., Heinze, G., Verde, P., & Calleja Gonzalez, J. (2021). HIGH-INTENSITY ACTIVITY ACCORDING TO PLAYING POSITION WITH DIFFERENT TEAM FORMATIONS IN SOCCER. *Acta Gymnica, 51*. https://doi.org/10.5507/ag.2021.003

Walker, S., & Turner, A. (2009). A One-Day Field Test Battery for the Assessment of Aerobic Capacity, Anaerobic Capacity, Speed, and Agility of Soccer Players. *Strength & Conditioning Journal, 31*(6), 52-60. https://doi.org/10.1519/SSC.0b013e3181c22085

Wehbe, G, M., Hartwig, T, B., & Duncan, C, S. (2014) Movement analysis of Australian national league soccer players using global positioning system technology. *Journal of Strength and Conditioning Research, 28(3)*, 834-842. https://doi.org/10.1519/JSC.0b013e3182a35dd1

Wei, Z., Yang, A., Rocha, L., Miranda, M. F., & Nathoo, F. S. (2022). A Review of Bayesian Hypothesis Testing and Its Practical Implementations. *Entropy*, *24*(2), 161. https://doi.org/10.3390/e24020161

Williams, M., Bååth, R., & Philipp, M. (2017). The Bayes factor: A bridge to Bayesian inference. *Submitted to Research in Human Development*.

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British Journal of Sports Medicine*, *38*(3), 285-288. https://doi.org/10.1136/bjsm.2002.002071

Wong, P.-l., Chaouachi, A., Chamari, K., Dellal, A., & Wisloff, U. (2010). Effect of Preseason Concurrent Muscular Strength and High-Intensity Interval Training in Professional Soccer Players. *The Journal of Strength & Conditioning Research*, *24*(3), 653-660. https://doi.org/10.1519/JSC.0b013e3181aa36a2

Young, W., Benton, D., & Pryor, J. M. (2001). Resistance Training for Short Sprints and Maximum-speed Sprints. *Strength & Conditioning Journal*, *23*(2), 7. https://doi.org/10.1519/00126548-200104000-00001

Part 2: Research study

The relationship between lab-sprint results and match physical performance in professional male soccer players

This paper is written in accordance with the guidelines of Scandinavian Journal of Medicine and Science in Sports

https://onlinelibrary.wiley.com/page/journal/16000838/homepage/forauthors.html?1

Kristian Sørlie Lunde

University of Agder

“The relationship between lab-sprint results and match physical performance in professional male soccer players”

Submission type: Original research

Kristian Sørlie Lunde

Faculty of Health and Sport Sciences, University of Agder, Kristiansand, Norway

Article written as part of a masters’ thesis in Sport Science. Co-authors: Matthew Spencer, Per Thomas Byrkjedal

Corresponding author:

Kristian Sørlie Lunde

University of Agder, Faculty of Health and Sport Sciences

Postboks 442, 4604 Kristiansand, Norway

Email: Kristiansl@uia.no

Telephone: +4795474005

Abstract

Aim: This research aims to examine the relationship between lab-sprint performance and match physical performance in professional male soccer players.

Methods: Eleven professional male soccer players (25.5 ± 3.4 years, 183.8 ± 5 cm, and 78.3 ± 4.9 kg) competing in the second-highest division in Norway participated in the research study. Sprinting performance was assessed by the players performing 30-m linear sprints at an indoor location using dual-beamed photocells, whereas match physical performance was monitored using a 10Hz GNSS device embedded with a 100Hz inertial movement unit (Catapult Vector S7) during seven official matches. Selected match play variables included total playing time, total duration, total distance, meters covered per minute, distance covered by high-speed running (19.8-25.2 km/h), distance covered by sprinting (>25.2 km/h), and maximal velocity (m/s).

Results: Moderate evidence was observed for the association between 5-m lab-sprint performance and distance covered by high-speed running (BF_{10}=4.9). Anecdotal evidence was observed for the association between 10-m, 15-m, 20-m, and 25-m lab-sprint performance and distance covered by high-speed running (BF_{10}=1.00-2.18). Similarly, anecdotal evidence was reported for the association between 10-m lab-sprint performance and peak speed during match play (BF_{10}=1.04), and peak lab-sprint speed and peak match play speed (BF_{10}=2.04).

Conclusion: The majority of the lab-sprint performance parameters did not show more than anecdotal evidence for associations with match physical performance. Thus, the 30-m lab-sprint test used in this research study did not reflect the players' physical abilities during match play.

Keywords: Elite football players, laboratory testing, sprint capacity, player monitoring, match play performance, high-speed actions.

Introduction

Soccer is a sport that requires players to frequently perform high-speed actions such as high-speed runs and sprints.[1] Data from the Norwegian top division suggests that professional soccer players cover approximately 800 ± 300 m and 200 ± 100 m during high-speed running and sprinting, respectively, which corresponds to approximately 8% of the total distance covered during a match.[2-4] Despite constituting a small portion of the total distance covered during a match, these actions are highly decisive for match outcome.[5] Analysis of goal scoring patterns in the German top division demonstrates the importance of high-speed actions, with the results revealing that 83% of goals scored occurred after a minimum of one powerful action by either the goal-scoring or assisting player.[5] Furthermore, 45 and 38% of goals scored occurred after linear sprints from the goal-scoring and assisting player, respectively.[5] The growing importance of high-speed actions in soccer is further supported by observations stating that professional players have become slightly faster in the last fifteen years, with acceleration and maximum sprint capacity possibly distinguishing players from different standards of play.[6] In addition to players becoming faster, observations from the English top division have reported significant increases in the frequency (~ 50%) and distance covered (~ 30%) by high-speed running in recent years.[7] Additionally, significant increases in the frequency (~ 85%) and distance covered (~35%) by sprinting were reported in the same period.[7]

Considering the increasing demands and importance of high-speed running and sprinting in soccer, 5-40 m linear sprint testing is recommended to assess and monitor players' physical abilities.[6,8] Even though linear sprint assessment is recommended for evaluating the physical abilities of soccer players, tactical factors during match play may modulate the relationship between sprint test results and match physical performance.[9] If soccer match play inhibits the utilization of players' maximal physical abilities, 5-40 m linear sprint testing may not reflect the actual physical ability of soccer players during match play. Concerning this, it is interesting to examine whether a 30-m lab-sprint test is capable of representing the physical aspects that are important for soccer match play performance. Thus, this research study aims to examine whether there is a meaningful relationship between lab-sprint performance and match physical performance in professional male soccer players.

Materials and Methods

Subjects

Twenty-six professional male soccer players belonging to the same club competing at the second-highest playing level in Norway were invited to participate in the project. Each subject gave their written consent for participation and were informed that they could withdraw at any time. The project was approved by the Norwegian center for research data and the ethical committee of the University of Agder prior to commencing the study. The research study was conducted in accordance with the declaration of Helsinki. Of the invited subjects, 11 players (25.5 ± 3.4 years, 183.8 ± 5 cm, and 78.3 ± 4.9 kg) met the inclusion criteria of performing the lab-sprint test and providing GNSS data of >60 minutes in a minimum of 4 matches during the data collection period.

Lab-sprint performance

Lab-sprint performance was assessed during a maximal 30-m linear sprint at an indoor location with dual-beamed photocells (MuscleLab 20, version 10.201.93.0, Ergotest, Porsgrunn, Norway) placed at 5-, 10-, 15-, 20-, 25- and 30-m, 1.6 m apart, and at 120 cm height. The subjects self-initiated the start from a stand-still upright position with a staggered stance with their preferred foot at the starting line, 0 cm from the first set of photocells, and the other foot placed further back. The distance from the front to the rear foot was self-determined based on individual preferences. The players were allowed to initiate the start by doing one small countermovement as long as both feet remained in full contact with the surface. Furthermore, the sprint test protocol consisted of three maximal sprints with four-minute rest intervals between all trials. However, the subjects were encouraged to perform one additional sprint if they recorded their best sprint time on the third trial. This protocol was maintained until the athlete failed to improve his time or was fatigued. The participants' single best sprinting time was collected and used in the data analysis.

Match physical performance

The subjects were monitored during seven official matches, including four home matches and three away matches, resulting in three wins, one draw, and three losses. A 10Hz global navigation satellite system (GNSS) device embedded with a 100Hz inertial movement unit (Catapult Vector S7, Catapult Sports, Melbourne, Australia) was used to assess external workload during match play. The GNSS device was placed in the garment pocket of a fitted vest, located between the players' scapulae with the players wearing the same vests and units to ensure interunit reliability during the data collection period.

Data processing

GNSS data included playing time (minutes), total duration (minutes), total distance covered, meters covered per minute, distance covered by high-speed running (19.8-25.2 km/h), distance covered by sprinting (>25.2 km/h) and maximal velocity (meters per second, m/s). The GNSS-derived match data were uploaded in the manufacturer's digital software OpenField (version 2.5.0) before being downloaded and organized in Microsoft Excel version 2203 (Microsoft Corporation, Redmon, WA, USA).

Statistical analysis

Lab-sprint results and GNSS variables were calculated using Microsoft Excel and presented as mean ± SD. To examine the relationship between the lab-sprint results and GNSS variables, a Bayesian correlation analysis with non-parametric Kendall's Tau-b correlation coefficients was conducted in JASP version 0.16.1.0. As the low sample size and the lack of statistical power in our research can lead to reliability issues,[10] a Bayesian approach was used to reduce the reliability issues concerning the small sample size and the lack of statistical power. Furthermore, the results are reported as Kendall's Tau-b and Bayes factor (Bf_{10}). The magnitude of Kendall’s Tau-b correlation coefficient is classified as 0.1 (small), 0.3 (moderate), 0.5 (large), 0.7 (very large) and 0.9 (extremely large).[11] The BF_{10} value is interpreted in line with previous research with BF_{10} 1-3 (anecdotal), BF_{10} 3-10 (moderate), BF_{10} 10-30 (strong), BF_{10} 30-100 (very strong) and BF_{10} >100 (extremely strong).[12]

Results

Descriptive statistics (Mean ± SD; minimum; maximum) of the lab-sprint results with 5-,10-,15-,20-,25-and 30-m split times and peak sprinting speed (m/s) are presented in table 1.

Table 1*: Descriptive statistics of lab-sprint results (N=11).*

Variables	Mean ± SD	Minimum	Maximum
5-m	0.81 ± 0.03	0.77	0.89
10-m	1.52 ± 0.05	1.44	1.65
15-m	2.16 ± 0.07	2.06	2.35
20-m	2.77 ± 0.10	2.63	3.01
25-m	3.35 ± 0.12	3.18	3.64
30-m	3.92 ± 0.15	3.71	4.27
Peak speed (m/s)	8.84 ± 0.43	7.97	9.42

M=Meters. M/s=Meters per second. Km/h=Kilometers per hour.

The GNSS match play data (Mean ± SD; minimum; maximum) are presented in table 2 and include match time, total duration, total distance covered, meters covered per minute, distance covered by high-speed running, distance covered by sprinting, and peak sprinting speed during match play.

***Table 2**: Average GNSS match play data (N=11, total observations=55).*

Variables	Mean ± SD	Minimum	Maximum
Match time	82.8 ± 6.8	69.5	90.0
Total duration	98 ± 1	96	99
Total distance	10 521 ± 1192	9042	12 583
Meters per minute	107.3 ± 11.7	92.9	126.8
High-speed running	599.4 ± 137.5	361.8	812.2
Sprint	118.5 ± 58.9	44.5	221.6
Peak speed (m/s)	8.16 ± 0.38	7.58	8.88

M/s=Meters per second. Km/h=Kilometers per hour.

Tables 3 and 4 present the relationships between the lab-sprint results and the GNSS match play variables as Kendall's Tau-b and BF_{10}, respectively.

Moderate evidence was observed for the association between 5-m lab-sprint time and distance covered by high-speed running during match play, whereas none of the other lab-sprint variables showed more than trivial associations with match physical performance.

In terms of the associations between lab-sprint variables, extremely strong evidence was shown for the association between lab-sprint times at 30- and 25-m, 25- and 20-m, 30- and 20-m, 20- and 15-m, 25- and 15-m, 30- and 15-m, 15- and 10-m, 20- and 10-m, respectively.

Furthermore, very strong evidence was found for the association between 25- and 10-m lab-sprint time, 30- and 10-m lab-sprint time, 30-m lab-sprint time and peak lab-sprint speed, 20-m lab-sprint time and peak lab-sprint speed, 5- and 10-m lab-sprint time, 25-m lab-sprint time and peak lab-sprint speed, 15-m lab-sprint time and peak lab-sprint speed, and 10-m lab-sprint time and peak lab-sprint speed.

Strong evidence was shown for the association between 15- and 5-m, 20- and 5-m, and 25- and 5-m lab-sprint times, whereas moderate evidence was observed for the association between 30- and 5-m lab-sprint time, 5-m lab-sprint time and peak lab-sprint speed.

Regarding the association between GNSS variables, extremely strong evidence was shown for the association between total distance covered and meters covered per minute. Moreover, moderate evidence was observed for the association between sprinting distance during match play and peak match play speed.

***Table 3**: Kendall's Tau-b correlation between lab-sprint performance and GNSS match play variables.*

	5-m	10-m	15-m	20-m	25-m	30-m	PS test	TD	MPM	HSR	Sprint	PS match
5-m												
10-m	0.80*											
15-m	0.72*	0.89*										
20-m	0.66*	0.86*	0.97*									
25-m	0.64*	0.83*	0.95*	0.99*								
30-m	0.62*	0.82*	0.94*	0.98*	0.99*							
PS test	-0.60*	-0.76*	-0.80*	-0.81*	-0.78*	-0.81*						
TD	0.15	0.20	0.09	0.04	0.02	0.00	-0.09					
MPM	0.22	0.17	0.06	0.00	-0.02	-0.04	-0.13	0.89*				
HSR	0.56*	0.46	0.43	0.37	0.35	0.33	-0.42	0.38	0.42			
Sprint	-0.08	-0.24	-0.28	-0.29	-0.27	-0.29	0.27	-0.09	-0.06	0.31		
PS match	-0.30	-0.35	-0.32	-0.33	-0.31	-0.33	0.46	-0.06	-0.13	0.42	0.60*	

-1.0 **0.0** **1.0**

Kendall's Tau-b correlation coefficient (range: -1 to 1) strength is displayed by graded color backgrounds.

M=Meters. PS test=Peak speed during lab-sprint tests. TD=Total distance. MPM=Meters per minute. HSR=High-speed running. PS match=Peak speed during match play.

* = >3 BF_{10}.

Table 4: The relationship between lab-sprint performance and GNSS match play variables reported as BF_{10}.

5-m	5-m	10-m	15-m	20-m	25-m	30-m	PS test	TD	MPM	HSR	Sprint	PS match
10-m	63.64											
15-m	25.79	194.60										
20-m	12.92	136.20	634.67									
25-m	10.01	96.85	430.27	833.14								
30-m	8.79	84.22	374.18	727.31	833.14							
PS test	6.93	38.93	38.93	69.70	50.92	69.70						
TD	0.45	0.53	0.40	0.38	0.38	0.38	0.40					
MPM	0.57	0.47	0.39	0.38	0.38	0.38	0.43	205.65				
HSR	4.90	2.18	1.67	1.14	1.00	0.92	1.58	1.25	1.58			
Sprint	0.39	0.61	0.71	0.77	0.69	0.77	0.69	0.40	0.39	0.83		
PS match	0.79	1.04	0.85	0.92	0.83	0.92	2.04	0.39	0.47	0.40	7.04	

<1 1-3 3-10 10-30 30-100 >100

Graded color scale representing: BF_{10} <1=Evidence for H0. BF_{10} 1-3=Anecdotal. BF_{10} 3-10=Moderate. BF_{10} 10-30=Strong. BF_{10} 30-100=Very strong. BF_{10} >100 =Extremely strong.
M=Meters. PS test=Peak speed during lab-sprint tests. TD=Total distance. MPM=Meters per minute. HSR=High-speed running. PS match=Peak speed during match play.

Discussion

This research study demonstrates the relationship between 30-m lab-sprint performance and GNSS-derived match physical performance in professional male soccer players. The main finding of this research study was moderate evidence for the association between 5-m lab-sprint performance and distance covered by high-speed running during match play, whereas the remaining lab-sprint variables did not show any meaningful associations to match physical performance.

The relationship between lab-sprint performance and match physical performance

To the researchers' knowledge, no previous studies have examined the relationship between lab-sprint performance and match physical performance in professional soccer players utilizing the same equipment and locomotive thresholds as used in this research study. Comparing such research can be challenging due to inconsistencies in locomotive thresholds and the utilization of different measuring methods. However, one study conducted on youth soccer players was partly similar to our research. 40-m GPS-measured lab-sprint performance and GPS-derived match physical performance were examined in youth soccer players with identical locomotive thresholds as our data collection.[13] Similar to our results, the authors did not find any correlation between peak lab-sprint speed, total distance covered (ρ=0.12, p=>0.05), and meters covered per minute (ρ=-0.24, p=>0.05). However, a large correlation between peak lab-sprint speed and distance covered by high-speed running (ρ=0.57, p=<0.05), sprinting (ρ=0.79, p=<0.05), and peak match play speed (ρ=0.77, p=<0.05) were found. Furthermore, several researchers have examined the relationship between peak lab-sprint speed (measured by photocells[9,14,15] and GPS[16,17]) and GPS-derived peak match play speed in youth,[9,14,17] semi-professional,[15] and professional[16] soccer players, resulting in various extent of correlation (r=0.52-0.84). Additionally, one study found significant correlations (r=0.74-0.86, p=<0.01) between photocell-measured 30-m lab-sprint time and video-derived peak speed during match play over three consecutive seasons in professional soccer players.[18] Furthermore, the validity and reliability of these studies are highly variable due to different measuring methods and testing/player monitoring protocols. For instance, two of the articles used 1Hz GPS devices[9,14], which may have compromised the validity and reliability of the speed measurements. Even though previous studies have shown large to very large correlations between peak lab-sprint speed and peak match play speed, most of these studies also found the players to attain approximately 90% of peak lab-sprint speed during match play. These results align with our findings, where the subjects attained 92% of their peak lab-sprint speed during match play. Additionally, research from the French top division suggest that professional soccer players reach >90% of peak speed 1-3 times during a match.[19] These results indicate that soccer players rarely obtain as fast average peak speeds during match play as during laboratory testing, which may question the ability of lab-sprint tests to reflect players' actual physical performance during match play.

Regarding the lower peak speed observed during match play compared to laboratory testing, several factors may prevent soccer players from reaching peak lab-sprint speed during match play. Firstly, soccer is a tactical sport that may lead to tactical constraints preventing players from reaching peak lab-sprint speed during match play, in addition to various contextual, situational, and environmental variables that may vary from match to match.[20] Moreover, the ability to reach peak speed during match play may be position-dependent.[14,19] These positional differences are probably related to the tactical roles and the available space for each playing position[14,19] as a wide midfielder, for instance, likely has more running space than a central midfielder.

Secondly, our lab-sprint assessment was conducted in a controlled indoor environment on a perfectly linear running track, which reduced the influence of environmental factors. Contrary to the lab-sprint running track, sprinting during match play is often curvilinear,[21] with the average sprinting angle being approximately 5°.[22] Additionally, players may have to react to external factors such as the movements of teammates and opponents during match play sprints, whereas the lab-sprint test consisted of uninterrupted acceleration throughout the full 30-m sprint. Based on this, it is possible that the occurrence of linear sprints during match play was relatively low, which may have prevented the players from reaching the same speeds as during lab-sprint testing. Additionally, the lab-sprint test was performed on a sports floor, whereas the match play sprinting was performed on artificial turf and grass wearing soccer boots, which possibly further differentiated the sprint performance in match play compared to the lab-sprint performance.

Thirdly, based on an average sprinting distance of 12.8 m during match play,[2] there is a possibility that the players did not reach sprinting distances of 30-m during match play, which may have affected their ability to reach peak lab-sprint speed, despite the majority of sprints starting from a moving start.[23] Moreover, the congested match schedule may have influenced the players' ability to reach peak speeds due to issues of fatigue during match play, as peak sprinting speed can be influenced for up to 72 hours post-match.[24] Lastly, the match performance monitoring was performed towards the end of the season, which may have impacted match physical performance due to accumulated fatigue throughout the season.[2]

Lab-sprint performance

Compared to previous literature on indoor photocell-measured sprint performance in professional male soccer players, our subjects obtained faster 5-m times than those reported in Croatian,[25] Danish,[26] Polish,[27] Portuguese,[28] and Spanish[29] top division players, and Brazilian state and national championship players.[30] Similarly, our subjects achieved greater 10-m times than previously observed in the English,[31-32] Norwegian,[33-35] and Polish[27] top division in addition to those reported in Brazilian state and national championship players.[30] However, results from Norwegian national team players[36] showed greater 10-m sprint performance than those reported in our research study. Regarding 20-m performance, our subjects were faster than those reported for players from the Croatian,[25] English,[32] Norwegian[35] and Polish[27] top division, in addition to those observed in the Brazilian state and national championship players,[30] but slower than the Norwegian national team players.[36] Lastly, our subjects obtained faster sprinting times at 30-m than the players from the Danish,[26] English,[32] Norwegian,[33] Portuguese,[28] and Polish[27] top division. However, the Norwegian national team players[36] reported faster 30-m sprinting times than our subjects.

The differences in sprinting speed observed in our subjects compared to the research above may be multifactorial. Firstly, several of the studies utilized single-beamed photocells, which have been reported to provide lower accuracy than dual-beamed photocells.[37] Secondly, the sprinting assessment in our research was performed in season, which may have influenced the results compared to those performed in pre-season. Thirdly, factors such as distance from the starting line, starting method, photocell placement, surface, and footwear may also have influenced the results.[37] Additionally, our sample size was relatively small, which may have led to the sprinting results not being representative of the sprint capacity of the rest of the team. Furthermore, the greater sprinting performance observed in[36] may have been due to the subjects consisting of national team players, whereas our subjects played at the second-highest division in Norway. This aligns with the suggestion that players at higher playing levels possess greater sprinting capacities than players at lower levels.[6] Another possible explanation for the greater sprint performance in the national players[36] involves the utilization of a start pad to initiate the sprint, which has been shown to produce faster sprinting times than initiating the sprint by breaking photocell beams.[37]

Limitations

The moderate evidence for the association between 5-m lab-sprint performance and high-speed running during match play should be interpreted with caution, as it may be a product of methodological issues related to the reliability of photocell-measured short sprints. Previous research suggests that CV increases simultaneously as sprinting distance decreases, with 0-20 m sprints having a CV of 1.82%, whereas 0-10 m sprints obtained a CV of 2.91%.[38]

Another limitation of this research study is the low number of subjects. The low sample size ruled out the possibility of categorizing the players into playing positions, which could have been beneficial due to positional differences in match physical performance.[2-4] For instance, this research study's low number of attackers (n=2) may have influenced the distance covered by high-speed running and sprinting, as attackers generally perform more high-speed running and sprints than central midfielders or central defenders.[3-4] Moreover, the data collection period consisted of relatively few matches (n=7), with players reaching the playing time threshold in 4-7 matches, resulting in certain players providing as many as three more observations than players at the lower end of the playing time threshold. Lastly, the locomotive outputs may have been influenced by various contextual, situational, and environmental factors such as match location, opposition standard, match importance, tactical factors, match status (win, draw, lose), and pre-match recovery status.[19]

Perspectives

The aim of this research study was to examine the relationship between 30-m lab-sprint performance and match physical performance in professional male soccer players. The results showed that the majority of the lab-sprint variables did not exhibit meaningful associations with match physical performance. Moreover, these results suggest that 30-m linear lab-sprint testing may not reflect the actual physical abilities of professional soccer players during match play. Thus, more knowledge is needed on measuring methods that better reflect the physical performance of professional players during match play.

Acknowledgments

The authors would like to thank all the people involved in the project, and especially the subjects for their efforts.

Conflicts of interest

The authors have no conflict of interest.

References

1. Bradley P, Sheldon W, Wooster B, Olsen P, Boanas P, Krustrup P. High-intensity running in English FA Premier League Soccer Matches. Journal of sports sciences. 2009;27:159-68.
2. Ingebrigtsen J, Dalen T, Hjelde GH, Drust B, Wisløff U. Acceleration and sprint profiles of a professional elite football team in match play. European Journal of Sport Science. 2015;15(2):101-10.
3. Dalen T, Jørgen I, Gertjan E, Geir Havard H, Ulrik W. Player Load, Acceleration, and Deceleration During Forty-Five Competitive Matches of Elite Soccer. The Journal of Strength & Conditioning Research. 2016;30(2):251-9.
4. Sæterbakken A, Haug V, Fransson D, Grendstad HN, Gundersen HS, Moe VF, et al. Match Running Performance on Three Different Competitive Standards in Norwegian Soccer. Sports Medicine International Open 2019;3(3):E82-E8.
5. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. Journal of Sports Sciences 2012;30(7):625-31.
6. Haugen TA, Tønnessen E, Hisdal J, Seiler S. The Role and Development of Sprinting Speed in Soccer. International Journal of Sports Physiology and Performance 2014;9(3):432-41.
7. Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. The evolution of physical and technical performance parameters in the English Premier League. International Journal of Sports Medicine 2014;35(13):1095-100.

8. Walker S, Turner A. A One-Day Field Test Battery for the Assessment of Aerobic Capacity, Anaerobic Capacity, Speed, and Agility of Soccer Players. Strength & Conditioning Journal. 2009;31(6):52-60.
9. Mendez-Villanueva A, Buchheit M, Simpson B, Peltola E, Bourdon P. Does On-Field Sprinting Performance in Young Soccer Players Depend on How Fast They Can Run or How Fast They Do Run? The Journal of Strength & Conditioning Research. 2011;25(9).
10. Button KS, Ioannidis JPA, Mokrysz C, Nosek BA, Flint J, Robinson ESJ, et al. Power failure: why small sample size undermines the reliability of neuroscience. Nature Reviews Neuroscience. 2013;14(5):365-76.
11. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41(1):3-13.
12. Quintana DS, Williams DR. Bayesian alternatives for common null-hypothesis significance tests in psychiatry: a non-technical guide using JASP. BMC Psychiatry. 2018;18(1):178.
13. Smalley B, Bishop C, Maloney S. "Small Steps, or Giant Leaps?" Comparing Game Demands of U23, U18, and U16 English Academy Soccer and Their Associations with Speed and Endurance. International Journal of Sports Science & Coaching 2021;17(1):134-42.
14. Al Haddad H, Simpson B, Buchheit M, Di Salvo V, Mendez-Villanueva A. Peak Match Speed and Maximal Sprinting Speed in Young Soccer Players: Effect of Age and Playing Position. International Journal of Sports Physiology and Performance 2015;10(7):888-96.
15. Massard T, Eggers T, Lovell R. Peak speed determination in football: is sprint testing necessary? Science and Medicine in Football 2017;2(2):1-4.
16. Djaoui L, Chamari K, Owen AL, Dellal A. Maximal Sprinting Speed of Elite Soccer Players During Training and Matches. The Journal of Strength & Conditioning Research 2017;31(6):1509-17.
17. Kyprianou E, Di Salvo V, Lolli L, Al Haddad H, Villanueva AM, Gregson W, et al. To Measure Peak Velocity in Soccer, Let the Players Sprint. Journal of Strength and Conditioning Research 2022;36(1):273-6.
18. Altmann S, Kuberczyk M, Ringhof S, Neumann R, Woll A. Relationships between performance test and match-related physical performance parameters. German Journal of Exercise and Sport Research 2018;48(2):218-27.
19. Buchheit M, Simpson BM, Hader K, Lacome M. Occurrences of near-to-maximal speed-running bouts in elite soccer: insights for training prescription and injury mitigation. Science and Medicine in Football 2021;5(2):105-10.
20. Paul DJ, Bradley PS, Nassis GP. Factors affecting match running performance of elite soccer players: shedding some light on the complexity. International Journal of Sports Physiology and Performance 2015;10(4):516-9.
21. Caldbeck P. CONTEXTUAL SPRINTING IN PREMIER LEAGUE FOOTBALL. [Doctoral thesis]: Liverpool John Moores University; 2020.
22. Fitzpatrick J, Linsley A, Musham C. Running the curve: a preliminary investigation into curved sprinting during football match-play. Sport Performance & Science Reports. 2019;1.
23. Di Salvo V, Baron R, González-Haro C, Gormasz C, Pigozzi F, Bachl N. Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. Journal of Sports Sciences 2010;28(14):1489-94.
24. Nedelec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G. The Influence of Soccer Playing Actions on the Recovery Kinetics After a Soccer Match. The Journal of Strength & Conditioning Research 2014;28(6):1517-23.

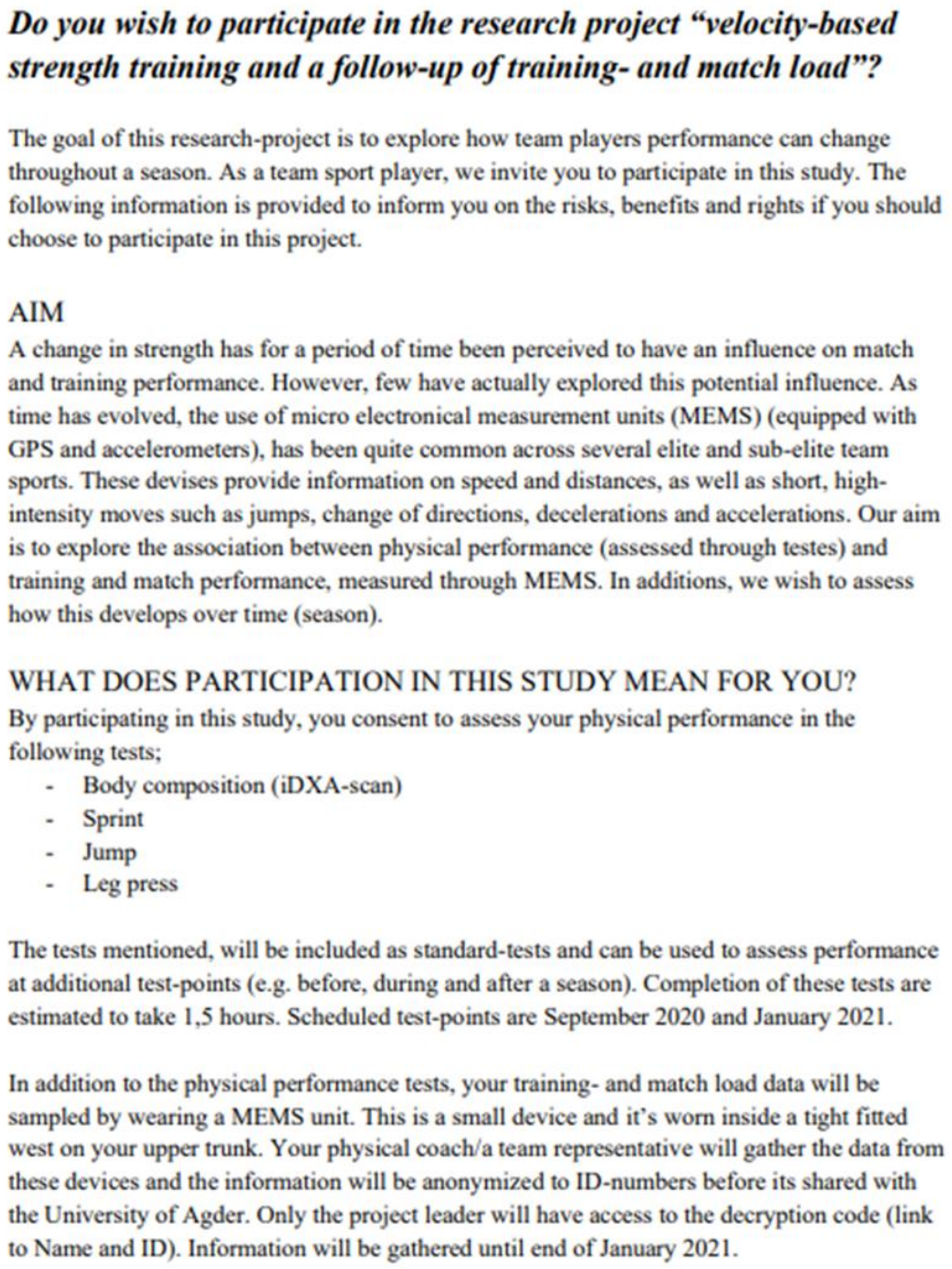
25. Sporis G, Jukic I, Ostojic SM, Milanovic D. Fitness profiling in soccer: physical and physiologic characteristics of elite players. Journal of Strength and Conditioning Research. 2009;23(7):1947-53.
26. Krommes K, Petersen J, Nielsen MB, Aagaard P, Hölmich P, Thorborg K. Sprint and jump performance in elite male soccer players following a 10-week Nordic Hamstring exercise Protocol: a randomised pilot study. BMC Research Notes. 2017;10(1):669.
27. Drozd M, Krzysztofik M, Nawrocka M, Krawczyk M, Kotuła K, Langer A, et al. Analysis of the 30-m running speed test results in soccer players in third soccer leagues. Turkish Journal of Kinesiology. 2017;3(1):1-5.
28. Silva JR, Magalhães J, Ascensão A, Seabra AF, Rebelo AN. Training Status and Match Activity of Professional Soccer Players Throughout a Season. The Journal of Strength & Conditioning Research. 2013;27(1):20-30.
29. Gorostiaga EM, Llodio I, Ibáñez J, Granados C, Navarro I, Ruesta M, et al. Differences in physical fitness among indoor and outdoor elite male soccer players. European Journal of Applied Physiology. 2009;106(4):483-91.
30. Gil S, Barroso R, Carmo E, Loturco I, Kobal R, Tricoli V, et al. Effects of resisted sprint training on sprinting ability and change of direction speed in professional soccer players. Journal of Sports Sciences 2018;36(17):1923-9.
31. Little T, Williams AG. Specificity of acceleration, maximum speed, and agility in professional soccer players. Journal of Strength and Conditioning Research. 2005;19(1):76-8.
32. Cotte T, Chatard J-C. Isokinetic strength and sprint times in English Premier League football players. Biology of Sport. 2011;28(2):89-94.
33. Wisløff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. British Journal of Sports Medicine. 2004;38(3):285-8.
34. Rønnestad B, Kvamme N, Sunde A, Raastad T. Short-Term Effects of Strength and Plyometric Training on Sprint and Jump Performance in Professional Soccer Players. Journal of Strength and Conditioning Research / National Strength & Conditioning Association 2008;22(3):773-380.
35. Helgerud J, Rodas G, Kemi O, Hoff J. Strength and Endurance in Elite Football Players. International Journal of Sports Medicine 2011;32(9):677-82.
36. Haugen T, Tønnessen E, Seiler S. Anaerobic Performance Testing of Professional Soccer Players 1995–2010. International Journal of Sports Physiology and Performance 2013;8(2):148-56.
37. Haugen T, Buchheit M. Sprint Running Performance Monitoring: Methodological and Practical Considerations. Sports Medicine. 2016;46(5):641-56.
38. Haugen TA, Tønnessen E, Seiler S. Speed and Countermovement-Jump Characteristics of Elite Female Soccer Players, 1995–2010. International Journal of Sports Physiology and Performance. 2012;7(4):340-9.

Part 3: Appendices

Kristian Sørlie Lunde

University of Agder

Appendix 1: Information about participation in the project



Do you wish to participate in the research project "velocity-based strength training and a follow-up of training- and match load"?

The goal of this research-project is to explore how team players performance can change throughout a season. As a team sport player, we invite you to participate in this study. The following information is provided to inform you on the risks, benefits and rights if you should choose to participate in this project.

AIM

A change in strength has for a period of time been perceived to have an influence on match and training performance. However, few have actually explored this potential influence. As time has evolved, the use of micro electronical measurement units (MEMS) (equipped with GPS and accelerometers), has been quite common across several elite and sub-elite team sports. These devises provide information on speed and distances, as well as short, high-intensity moves such as jumps, change of directions, decelerations and accelerations. Our aim is to explore the association between physical performance (assessed through testes) and training and match performance, measured through MEMS. In additions, we wish to assess how this develops over time (season).

WHAT DOES PARTICIPATION IN THIS STUDY MEAN FOR YOU?

By participating in this study, you consent to assess your physical performance in the following tests;

- Body composition (iDXA-scan)
- Sprint
- Jump
- Leg press

The tests mentioned, will be included as standard-tests and can be used to assess performance at additional test-points (e.g. before, during and after a season). Completion of these tests are estimated to take 1,5 hours. Scheduled test-points are September 2020 and January 2021.

In addition to the physical performance tests, your training- and match load data will be sampled by wearing a MEMS unit. This is a small device and it's worn inside a tight fitted west on your upper trunk. Your physical coach/a team representative will gather the data from these devices and the information will be anonymized to ID-numbers before its shared with the University of Agder. Only the project leader will have access to the decryption code (link to Name and ID). Information will be gathered until end of January 2021.

PRO's AND CON's ASSOCIATED WITH PARTICIPATION IN THIS PROJECT

As a participant in this project, you will be provided and given insight to scientific test-results of your physical performance. However, there are some potetial disadvantages if you choose to participate in this project:

- You have to make time (ca 1,5 hours) for each test day. Time you may wished to spend at your own choosing.
- Testing and training may be associated with muscle soreness and a discomfort.
- There always a risk of injuries during training and testing, but the risks are not expected to proceed the risks experienced during your daily training regime.
- A body composition scan (iDXA) is performed by X-ray and includes a small dose of radiation. This radiation dose is equivalent to the dose you experience during an intercontinental flight.

WHAT WILL HAPPEN TO YOUR PERSONAL INFORMATION?

We will only use the information as described in this letter. Your information will be treated confidentially and in accordance with the guidelines for personal data protection. All personal information will be anonymized. No information will be saved under your name, but under an ID-code, only decryptable by a decryption-key stored locally in a safe at the Institute of Sport Science and Physical Education offices at the University of Agder, Kristiansand. Only the project leader will have access to this safe. Your personal information will not be identifiable in research publications.

The project is scheduled to be terminated 31.01.21 an all data will thereby be anonymized. Your anonymized data will be stored for 5 years as we are obligated to store this and a decrypted name-lists for 5 years after termination of the project. This is for verification and control of the results. After these 5 years, all data from the project will be deleted.

Your rights; as long as you can be identified in the data-material, you have a right to;

- Have insight in personal material registered on you.
- Have your information corrected
- Have personal information deleted
- Have access to a copy of your personal information
- Make a complaint to a data protection official or the Norwegian data protection Authority regarding the processing of your personal information

Who gives us (the University of Agder) a right to process your personal information?

- We process your personal information by your written consent.

The Norwegian center for research data has on request by the University of Agder concluded that the processing of your personal information is in accordance with the personal information privacy policy.

VOLUNTARY PARTICIPATION

Your participation in this project is voluntary and you can at any point and for any reason withdraw yourself from the study without giving any reason for this. All your information will then be anonymized. There is no negative consequence for you if you choose not to participate or withdraw yourself from the project.

If you have any questions to the study, or wish to use your rights, please contact the project-leaders Per Thomas Byrkjedal (Doktorgradsstipendiat: per.byrkjedal@uia.no / 93498951) or Thomas Bjørnsen (thomas.bjornsen@uia.no / 986 19 299), our data protection official Ina Danielsen, Universitetet i Agder, ina.danielsen@uia.no, phone +47 452 54 401 or Norwegian center for research data (NSD) (personverntjenester@nsd.no / 55 58 21 17). The institution responsible for the project is the University of Agder.

Best regards

Thomas Bjørnsen & Per Thomas Byrkjedal

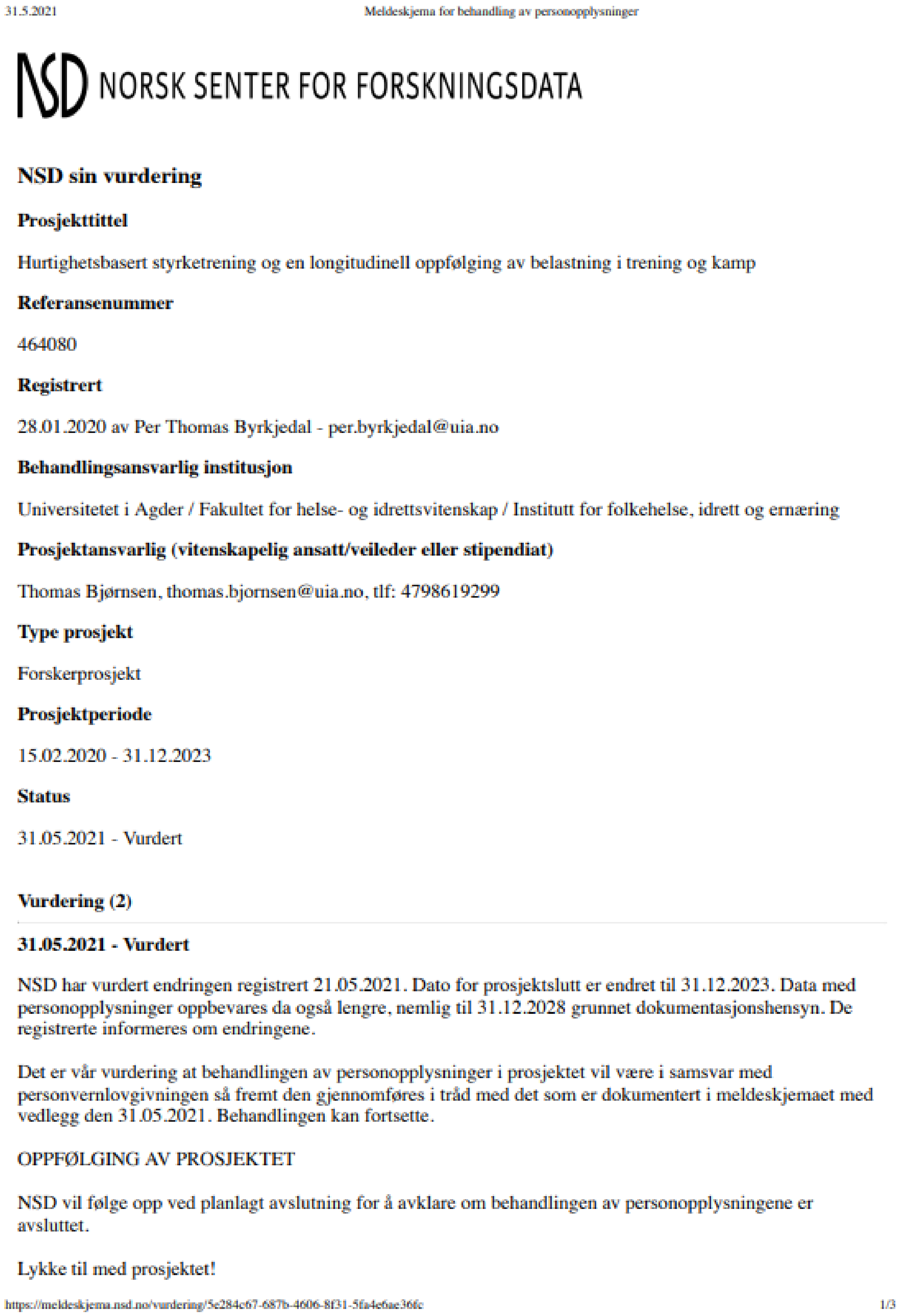
CONSENT-FORM

I have received and understood the information related to participation in the project *velocitybased strength training and a follow-up of training- and match load* and I've been given the chance to ask questions. I hereby consent to

- ☐ participate in the study
- ☐ that my personal information can be procced in an anonymized form until all data related to the project is deleted 31.01.26

---------------------	---
(Date)	(Signature participant)

Appendix 2: Approval from the Norwegian center for research data



NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

Hurtighetsbasert styrketrening og en longitudinell oppfølging av belastning i trening og kamp

Referansenummer

464080

Registrert

28.01.2020 av Per Thomas Byrkjedal - per.byrkjedal@uia.no

Behandlingsansvarlig institusjon

Universitetet i Agder / Fakultet for helse- og idrettsvitenskap / Institutt for folkehelse, idrett og ernæring

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Thomas Bjørnsen, thomas.bjornsen@uia.no, tlf: 4798619299

Type prosjekt

Forskerprosjekt

Prosjektperiode

15.02.2020 - 31.12.2023

Status

31.05.2021 - Vurdert

Vurdering (2)

31.05.2021 - Vurdert

NSD har vurdert endringen registrert 21.05.2021. Dato for prosjektslutt er endret til 31.12.2023. Data med personopplysninger oppbevares da også lengre, nemlig til 31.12.2028 grunnet dokumentasjonshensyn. De registrerte informeres om endringene.

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg den 31.05.2021. Behandlingen kan fortsette.

OPPFØLGING AV PROSJEKTET

NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til med prosjektet!

Tlf. Personverntjenester: 55 58 21 17 (tast 1)

17.02.2020 - Vurdert

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet den 17.02.2020 med vedlegg, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde:
https://nsd.no/personvernombud/meld_prosjekt/meld_endringer.html
Du må vente på svar fra NSD før endringen gjennomføres.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle særlige kategorier av personopplysninger om helseopplysninger og alminnelige kategorier av personopplysninger frem til 31.12.2021. Data med personopplysninger oppbevares deretter internt ved behandlingsansvarlig institusjon frem til 31.12.2026, dette til forskningsformål.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 nr. 11 og art. 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse, som kan dokumenteres, og som den registrerte kan trekke tilbake.

Lovlig grunnlag for behandlingen vil dermed være den registrertes uttrykkelige samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a, jf. art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 (2).

PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om:

- lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet

DE REGISTRERTES RETTIGHETER
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: åpenhet (art. 12), informasjon (art. 13), innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18), underretning (art. 19), dataportabilitet (art. 20).

NSD vurderer at informasjonen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Catapult Sports er databehandler i prosjektet. NSD legger til grunn at behandlingen oppfyller kravene til bruk av databehandler, jf. art 28 og 29.

For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og eventuelt rådføre dere med behandlingsansvarlig institusjon.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp underveis (hvert annet år) og ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet/pågår i tråd med den behandlingen som er dokumentert.

Lykke til med prosjektet!

Kontaktperson hos NSD: Mathilde Hansen
Tlf. Personverntjenester: 55 58 21 17 (tast 1)

Appendix 3: Approval from the Faculty ethics committee

UiA Universitetet i Agder

Per Thomas
Byrkjedal

Besøksadresse:
Universitetsveien 25
Kristiansand

Ref: [object Object]

Tidspunkt for godkjenning: : 28/02/2020

Søknad om etisk godkjenning av forskningsprosjekt - Hurtighetsbasert styrketrening og en longitudinell oppfølging av belastning i trening og kamp

Vi informerer om at din søknad er ferdig behandlet og godkjent.

Kommentar fra godkjenner:
FEK godkjenner søknaden under forutsetning av at prosjektet gjennomføres som beskrevet i søknaden.

Hilsen
Forskningsetisk komite
Fakultet for helse - og idrettsvitenskap
Universitetet i Agder

UNIVERSITETET I AGDER
POSTBOKS 422 4604 KRISTIANSAND
TELEFON 38 14 10 00
ORG. NR 970 546 200 MVA - post@uia.no -
www.uia.no

FAKTURAADRESSE:
UNIVERSITETET I AGDER,
FAKTURAMOTTAK
POSTBOKS 383 ALNABRU 0614 OSLO